CONTAMINANTS IN FISH FROM CALIFORNIA RIVERS AND STREAMS, 2011

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EXECUTIVE SUMMARY E

In 2011, the Surface Water Ambient Monitoring Program (SWAMP) conducted a screening survey of contaminants in sport fish in California rivers and streams. This was the last in a series of three surveys investigating sport fish contamination in California waters. The two previous surveys were conducted in lakes (2007-2008) and coastal waters (2009-1010). Sport fish were sampled from popular fishing areas in rivers and streams throughout the state and tested for contaminants[1] with the potential for exceeding established levels of concern.

This survey was designed to address two management questions.

1. Status of the Fishing Beneficial Use: *For popular fish species, what percentage of popular fishing areas have low enough concentrations of contaminants that fish can be safely consumed?*
2. Need for Further Sampling: *Should additional sampling of contaminants in sport fish (e.g., more species or larger sample size) in specific areas be conducted for the purposes of developing comprehensive consumption guidelines?*

In this Survey, 568 fish representing 16 species were collected from 63 river and stream locations throughout California. The species selected for sampling included those known to accumulate high concentrations of contaminants and therefore serve as informative indicators of potential contamination problems. Contaminant concentrations in fish tissue were evaluated using thresholds developed by the California Office of Environmental Health Hazard Assessment (OEHHA).

The sampling design called for analysis of multiple species at each location, and significant variation among species was observed. Considering the species that are typically cleaner, low concentrations of contaminants were found at the vast majority of the locations sampled. Considering the species that are typically more contaminated, the Survey documented widespread moderate impact and a limited area of high impact of bioaccumulative contaminants on the fishing beneficial use.

Methylmercury is the contaminant that poses the greatest concern for consumers of fish caught in California rivers and streams. Most locations of the 63 locations sampled (51%) had low concentrations of methylmercury (< 0.07 ppm). This represents an estimate of the percentage of locations where frequent consumption of fish is likely to be safe with regard to methylmercury. Eight of the locations (13%) were in the high contamination category, with an average for the most contaminated species exceeding 0.44 ppm. Fifteen locations (24%) had a species above 0.22 ppm. Overall, 87% of the locations had a most highly contaminated species with an average methylmercury concentration below 0.44 ppm. Specific recommended consumption frequencies will be determined by OEHHA when sufficient data are available for this type of evaluation.

1. methylmercury, PCBs, dieldrin, DDTs, chlordanes, and selenium

Most of the locations in the high contamination category were in the Sacramento-San Joaquin Delta and its nearby tributaries. The patterns observed in the Delta region in the present Survey are in close agreement with the patterns observed in past sampling, with high concentrations around the periphery of the Delta and lower concentrations in the central Delta. The only other location with a concentration in the high category was the Laguna de Santa Rosa in Sonoma County.

River and stream locations outside of the Delta region all had low or moderate methylmercury contamination, with the sole exception of Laguna de Santa Rosa. At many of these locations, rainbow trout was the only target species that could be collected. Rainbow trout were collected at 40 locations and had low concentrations (less than 0.07 ppm) at 34 (85%) of those locations. Limited sampling of other trout species and Chinook salmon also yielded low average concentrations.

Few data are available to support a robust assessment of long-term trends in methylmercury concentrations in sport fish in California rivers and streams. A lack of rigorous trend monitoring is an important information gap for methylmercury and other contaminants in these water bodies.

Concentrations of the other contaminants measured (PCBs, selenium, and the legacy pesticides dieldrin, DDTs, and chlordanes) rarely exceeded OEHHA thresholds that would indicate a potential need for reduced consumption. The organic contaminants, however, did frequently exceed other thresholds that have been used for 303(d) listing determinations by some regional Water Boards.

Other less-contaminated species were frequently present alongside the species with high concentrations at the contaminated locations. This could indicate that safe fish consumption at a frequency of more than one serving per week is possible at the vast majority of these locations if the cleaner species are selected. Comparing the data to a high standard of safety, 28 of the 63 locations (44%) had at least one species that can be safely consumed at a higher consumption rate of 3 servings per week.

Results from this Survey will be used by the State and Regional Water Boards in prioritizing rivers and streams in need of cleanup plans or further monitoring. 303(d) listings and consumption advisories are already in place for many of the areas sampled in this Survey.

The following next steps are recommended with regard to monitoring the impacts of contaminants on beneficial uses in California rivers and streams:

1. more thorough sampling of species less abundant than rainbow trout in higher elevation water bodies to provide for a more accurate assessment of contaminant impacts on the fishing beneficial use;
2. establishment of stations where long-term time series are created using a rigorous sampling design to evaluate trends;
3. evaluation of methylmercury risks to wildlife dependent on river and stream habitat; and
4. monitoring of contaminants of emerging concern in fish from select river and stream locations.

In 2012 and 2013, SWAMP is assessing methylmercury exposure and risk in wildlife on California lakes and reservoirs. Specifically, this study is examining methylmercury concentrations in birds (Western Grebes and Clark's Grebes), the small fish they eat, and sport fish consumed by humans. Results from the first year of this study will be reported in early 2014.

SECTION 1 INTRODUCTION

BACKGROUND

Contaminants that accumulate in the food web (or "bioaccumulate") exceed levels of concern in water bodies throughout California, posing threats to the health of humans and wildlife that consume contaminated aquatic biota. Bioaccumulation of methylmercury, PCBs, and other contaminants has led to fish consumption advisories, 303(d) listings, and TMDLs in many locations across the state. Existing information on spatial patterns and temporal trends suggests that other locations that have either not been monitored or monitored less thoroughly may also have similar problems.

Recreational fishing is an important element of the California economy. Data gathered for 2006 indicate that there are over 1.2 million freshwater anglers in California that spend over 12.3 million days fishing per year (Allen and Southwick 2008). Another 760,000 anglers fish in saltwater habitats. Combined, these freshwater and saltwater anglers spent over $2.7 billion in 2006 in retail sales related to fishing, the fourth highest value among the 50 states. The overall impact on the California economy is estimated at $4.8 billion per year.

In spite of the importance of fisheries in rivers and streams to the economy and as a source of food for Californians, no systematic statewide monitoring of contaminants in fish from these habitats has yet been performed. This report summarizes results from a one-year statewide screening survey of contaminants in sport fish from California rivers and streams. The report represents a significant advance in understanding the extent of chemical contamination in sport fish across the state. The goals of the study were to:

1) define the spatial extent of contamination in fish relative to assessment thresholds developed by regulatory agencies; and
2) identify areas where further sampling should be conducted to support development of safe eating guidelines.

The results from this screening survey will be valuable in prioritizing areas in need of further study, supporting development of consumption guidelines and cleanup plans, and providing information the public can use to be better informed about the degree of contamination at their favorite fishing spots. The focus of the survey was on a set of contaminants that are of primary concern in California sport fish: methylmercury, PCBs, selenium, and legacy pesticides (DDTs, dieldrin, and chlordanes).

The survey described in this report was performed as part of the State Water Resources Control Board's Surface Water Ambient Monitoring Program (SWAMP). This effort is an element of the initial phase of a new long-term, statewide, comprehensive bioaccumulation monitoring program for California surface waters.

This report provides a concise technical summary of the findings of the survey. The target audience is agency scientists who are charged with managing water quality issues related to bioaccumulation of contaminants in California surface waters.

Oversight for this program is being provided by the SWAMP Roundtable. The Roundtable is composed of State and Regional Board staff and representatives from other agencies and organizations including the US Environmental Protection Agency (USEPA), the California Department of Fish and Wildlife (CDFW), and the California Office of Environmental Health Hazard Assessment (OEHHA). Interested parties, including members of other agencies, consultants, or other stakeholders, also participate.

The Roundtable formed a committee, the Bioaccumulation Oversight Group (BOG), to guide SWAMP bioaccumulation monitoring. The BOG includes representatives from each of the Roundtable groups; in addition, it includes the San Francisco Estuary Institute. The members of the BOG have extensive experience with bioaccumulation monitoring. The BOG also serves as a workgroup of the California Water Quality Monitoring Council (http://www.waterboards.ca.gov/mywaterquality/monitoring_council/). The Council's objectives are to promote coordination and cost-effectiveness of water quality and ecosystem monitoring and assessment, enhance the integration of monitoring data across departments and agencies, and increase public access to monitoring data and assessment information.

The BOG has also convened a Bioaccumulation Peer Review Panel that is providing evaluation and review of the bioaccumulation program. The members of the Panel are internationally-recognized authorities on bioaccumulation monitoring.

The BOG has developed and is implementing a plan to evaluate bioaccumulation impacts on the fishing beneficial use in all California water bodies. Sampling of sport fish in lakes and reservoirs was conducted in the first two years of monitoring (2007 and 2008) (Davis et al. 2010). In 2009 and 2010, sport fish from the California coast, including bays and estuaries, were sampled (Davis et al. 2011, 2012). Sport fish from rivers and streams were sampled in 2011, and the data from that sampling are presented in this report. A study of methylmercury exposure and risk in aquatic birds on lakes and reservoirs and a workshop on biotoxins is taking place in 2012 and 2013. In 2012 the BOG also developed a comprehensive strategy for enhancing coordination of bioaccumulation monitoring, assessment, and communication in aquatic ecosystems in California. Work in 2013 will include a second year of the study of methylmercury in birds on lakes and reservoirs and a review of existing information on biotoxins in California water bodies.

THE RIVERS AND STREAMS SURVEY

Management Questions for This Survey

Two management questions were articulated to guide the design of the Rivers and Streams Survey. These management questions are specific to this initial screening survey; different management questions may be established to guide later efforts.

Management Question 1 (MQ1)

Status of the Fishing Beneficial Use

For popular fish species, what percentage of popular fishing areas have low enough concentrations of contaminants that fish can be safely consumed?

Answering this question is critical to determining the degree of impairment of the fishing beneficial use across the state due to bioaccumulation. This question places emphasis on characterizing the status of the fishing beneficial use through monitoring of the predominant pathway of exposure – consumption of popular fish species from popular fishing areas. This focus is also anticipated to enhance public and political support of the program by assessing the resources that people care most about. The determination of percentages mentioned in the question captures the need to perform an assessment of the entire state. Past monitoring of contamination in sport fish in California rivers and streams has been patchy (reviewed in Davis et al. [2007]), and a systematic survey of the entire state has never been performed. The emphasis on safe consumption calls for an accurate message on the status of the fishing beneficial use and evaluation of the data using thresholds for safe consumption.

The data needed to answer this question are average concentrations in popular fish species from popular fishing locations. Inclusion of as many popular species as possible is important to understanding the nature of impairment in any areas with concentrations above thresholds. In some areas, some species may have low concentrations while others do not, and this is valuable information. Monitoring of species that are known to accumulate high concentrations of contaminants ("indicator species") is valuable in answering Management Question 1: if concentrations in these species are below thresholds, this is a strong indication that an area has low concentrations.

OEHHA uses these same types of data in development of safe eating guidelines. While the data generated for this study are intended to be usable for that purpose, this study did not generate sufficient information for development of safe eating guidelines and the assessments presented in this report should not be construed as consumption advice.

Management Question 2 (MQ2)

Need for Further Sampling

Should additional sampling of contaminants in sport fish (e.g., more species or larger sample size) in specific areas be conducted for the purpose of developing comprehensive consumption guidelines?

This screening survey of California rivers and streams will provide a preliminary indication as to whether areas that have not been sampled thoroughly to date may require consumption guidelines. Consumption guidelines provide a mechanism for reducing human exposure in the near-term. OEHHA, the agency responsible for issuing consumption guidelines, considers a sample of 9 or more fish from a variety of species abundant in a water body to be the minimum needed in order to issue guidance. It is valuable to have information not only on the species with high concentrations, but also on the species with low concentrations so anglers can be encouraged to target the less-contaminated species. Answering this question is essential as a first step in determining the need for more thorough sampling in support of developing consumption guidelines.

OVERALL APPROACH

The overall approach taken to answer these two questions was to perform a statewide screening study of bioaccumulation in sport fish in California rivers and streams. Answering these questions, as has been done for lakes and reservoirs and the coast, provides a basis for decision-makers to understand the scope of the bioaccumulation problem both in rivers and streams and across all of these water body types. It also provides regulators with information to guide policy and management actions as well as risk communication relating to consumption of sport fish.

It is anticipated that the screening study may lead to more detailed followup investigations of areas where consumption guidelines and cleanup actions are needed. Funding for these followup studies will come from other local or regional programs rather than the SWAMP statewide monitoring budget.

The approach in this study is consistent with the approaches taken in the previous statewide surveys of bioaccumulation in California lakes and reservoirs (Davis et al. 2010) and on the California coast (Davis et al. 2012). Adding information on bioaccumulation in rivers and streams to that already obtained for the other water body types completes a comprehensive statewide assessment of the impact of contaminants on the fishing beneficial use in California.

Through coordination with other programs, SWAMP funds for this survey were leveraged to promote efficient use of the limited funds available for monitoring related to bioaccumulation in California.

One significant collaboration was with the Central Valley Regional Water Quality Control Board (CVRWQCB). The CVRWQCB provided $16,000 for supplemental sampling at 13 sites to support development of a mercury TMDL for the Sierra Nevada foothill region. The additional fish species collected coincided with the secondary target list for this study (Sacramento pikeminnow, Sacramento sucker, etc. – see Table 3 in the Sampling Plan [Bioaccumulation Oversight Group 2011]).

This survey was also coordinated with a study conducted by the U.S. Geological Survey (USGS) and funded by the State Board to develop assessment tools for evaluating mercury cleanups and for making 303(d) listing decisions (http://ca.water.usgs.gov/projects/2011-07.html). The $700,000 project was designed to validate the use of sediment mercury concentration data for 303(d) listings. The project began in 2011 with a review of existing data, followed by sampling to fill data gaps in 2012. The project attempted to establish a consistent relationship between mercury bioaccumulation in fish tissue and sediment total mercury. The study conducted sampling at 20 stream reaches and 13 lakes and reservoirs in gold mining regions of the Sierra Nevada foothills. Sampling included fish tissue, sediment, and water. Coordination with the SWAMP survey allowed the USGS study to establish a more extensive empirical dataset to support the development of the assessment tools.

Coordination on a small scale also occurred with the Region 6 Water Board. In coordination with Region 6, microcystins were analyzed in fish collected from the station on the East Walker River below Bridgeport Reservoir. Microcystin is a toxin produced by cyanobacteria that can undergo blooms in eutrophic water bodies. Cyanobacteria blooms are known to occur in Bridgeport Reservoir in Region 6.

SECTION 2 METHODS

SAMPLING DESIGN

A sampling plan was developed to address the management questions for the project (Bioaccumulation Oversight Group 2011). Sampling was conducted at 63 locations (Figures 1 and 2). Fish were collected from April through October in 2011. Cruise reports with detailed information on locations are available at: http://www.waterboards.ca.gov/water_issues/programs/swamp/rivers_study.shtml

California has over 211,000 miles of rivers and streams (Davis et al. 2007) that include hundreds of popular sport-fishing locations and encompass a diverse array of landscapes, fish assemblages, and human impact. Conducting a statewide survey with a limited budget is a challenge. The approach employed to sample this vast area was to conduct a complete sampling (or census) of the entire group of the most popular river and stream fishing locations in the state. Popular fishing locations were identified from Stienstra (2004) and discussions with stakeholders. Stienstra (2004) rated fishing spots on a scale of 1 to 10 based on three elements: number of fish, size of fish, and scenic beauty. With the budget available for this survey we were able to sample all of the river and stream locations with a Stienstra rating of 6 or higher. Table 2 in the Sampling Plan (Bioaccumulation Oversight Group 2011) includes the Stienstra rating and other information regarding the rationale and specifications of each sampling location.

Consideration was also given to information obtained from, and priorities expressed by, staff from the Regional Water Boards. In some instances, Water Board staff were aware of popular locations not rated or not given a high rating by Stienstra (2004). In other instances, Water Board information needs were a factor that drove inclusion of particular locations.

In addition, the Survey included collection and analysis of anadromous species (salmon and steelhead) upon their return migration to three hatcheries for each species. This was considered to be the most efficient and appropriate approach to collecting these species that range throughout the river systems and are not closely connected with any particular location.

These considerations led to the spatial distribution of sampling locations shown in Figures 1 and 2. The small proportion of locations in southern California reflects the Stienstra ratings and the lower amount and quality of fishing activity on rivers and streams in this arid region.

The Sampling Plan (Bioaccumulation Oversight Group 2011) provides more details on the design: http://www.waterboards.ca.gov/water_issues/programs/swamp/rivers_study.shtml

RIVERS SURVEY 2011

Levels of Concern for Methylmercury and PCBs

Levels of Concern

	Low	Moderate	High
Methylmercury (parts per million)	<0.07	0.07 - 0.44	>0.44
PCBs (parts per billion)	<3.6	3.6 - 120	>120

	Station Name	Methyl-mercury	PCB
1	Klamath River (Iron Gate FH)	Low	Moderate
2	South Form Smith River near Goose Cr	Low	Low
3	Klamath River Above Boise Creek	Low	Low
4	McCloud River at Lower Falls below Fowlers Camp	Low	Low
5	Sacramento River near Castle Crags State Park	Low	Low
6	Fall River at Island Road near McArthur	Moderate	Low
7	Pit River at Big Bend	Low	Low
8	Mad River (Mad River Fish Hatchery)	Moderate	Low
9	Hat Creek downstream Old Station	Low	Low
10	Trinity River above Junction City	Moderate	Low
11	Susan River ~0.6mi above Jensen Slough	Low	Low
12	Van Duzen River downstream of Forest Road 1S07	Low	Low
13	Warner Creek 30	Moderate	Low
14	Sacramento River at Bend Bridge Near Red Bluff	Moderate	Low
15	Butte Creek near Butte Meadows	Low	Low
16	Feather River, North Fork above Beldon Bridge	Low	Low
17	Spanish Creek at Oakland Camp Road crossing	Low	Low
18	Feather River Middle Fork @ Sloat	Moderate	Moderate
19	Feather River, Middle Fork upstream Clio	Low	Low
20	Jamison Creek 82	Low	
21	Middle Truckee River, Below Canyon 24	Low	Low
22	Eel River (Van Arsdale Fishing Counting Station)	Low	Low
23	Yuba River, South Fork above Canyon Creek	Low	Low
24	Yuba River, South Fork upstream Lake Spaulding	Low	
25	Feather River upstream Yuba City	High	Low
26	South Yuba River at Van Norden Dam	Moderate	Low
27	Cold Creek at Potter Valley	Low	Low
28	Sacramento River at Colusa near Bridge Street	Moderate	Low
29	Russian River (Coyote Valley Dam Egg Collection)	Moderate	Low
30	American River, South Fork at Coloma	High	Moderate
31	West Fork Carson River, at HWY 89 (Hope Valley)	Low	Moderate
32	American River, Silver Fork	Low	Low
33	Carson River, East Fork upstream of Hangman's Bridge	Low	Moderate
34	American R @ Discovery Park	High	Moderate
35	Cosumnes River, Middle Fork at Pi Pi	Low	Low
36	Mokelumne River, NF below Grouse Cr.	Low	Low
37	Sacramento River at RM44	High	Moderate
38	Laguna de Santa Rosa at Occidental Rd	High	Moderate
39	West Walker River, near Chris Flat Campground	Low	Low
40	East Walker River below Bridgeport Reservoir	Moderate	Low
41	Mokelumne River u/s Pardee Reservoir	Moderate	Moderate
42	Mokelumne River near I-5	High	Moderate
43	Buckeye Cr, above Eagle Cr (abv campground)	Low	Low
44	Mokelumne River (Mokelumne River FH)	Moderate	Moderate
45	Virgina Cr, below Willow Springs (at USGS gage)	Moderate	Moderate
46	San Joaquin River off Pt Antioch near fishing pier	High	Moderate
47	Middle River near Empire Cut	Moderate	Moderate
48	San Joaquin R at Louis Park	Moderate	Moderate
49	Lee Vining Cr, at Moraine Camp	Low	Moderate
50	Tuolumne River below Forest Route 1N07 Bridge	Moderate	Moderate
51	San Joaquin River at Vernalis (FMP)	Moderate	Low
52	Merced River at El Portal Foresta Road	Low	
53	San Joaquin River, Middle Fork near Agnew Meadows	Low	Low
54	Merced River below Briceburg Bridge	Moderate	Low
55	Owens River at Hwy 6	Low	Low
56	San Joaquin River at Lander Avenue	High	Low
57	Bishop Creek below Bishop Park Campground	Low	Moderate
58	Big Pine Creek above Big Pine Campground	Moderate	Low
59	Independence Creek at Grays Meadow Campground	Moderate	Low
60	Lone Pine Creek at Whitney Portal Campground	Low	Low
61	Kern River Below Fairview Campground	Moderate	Low
62	Santa Ana River Northwest of South Fork Campgrounds	Moderate	Low
63	Colorado River at Blythe	Moderate	Low

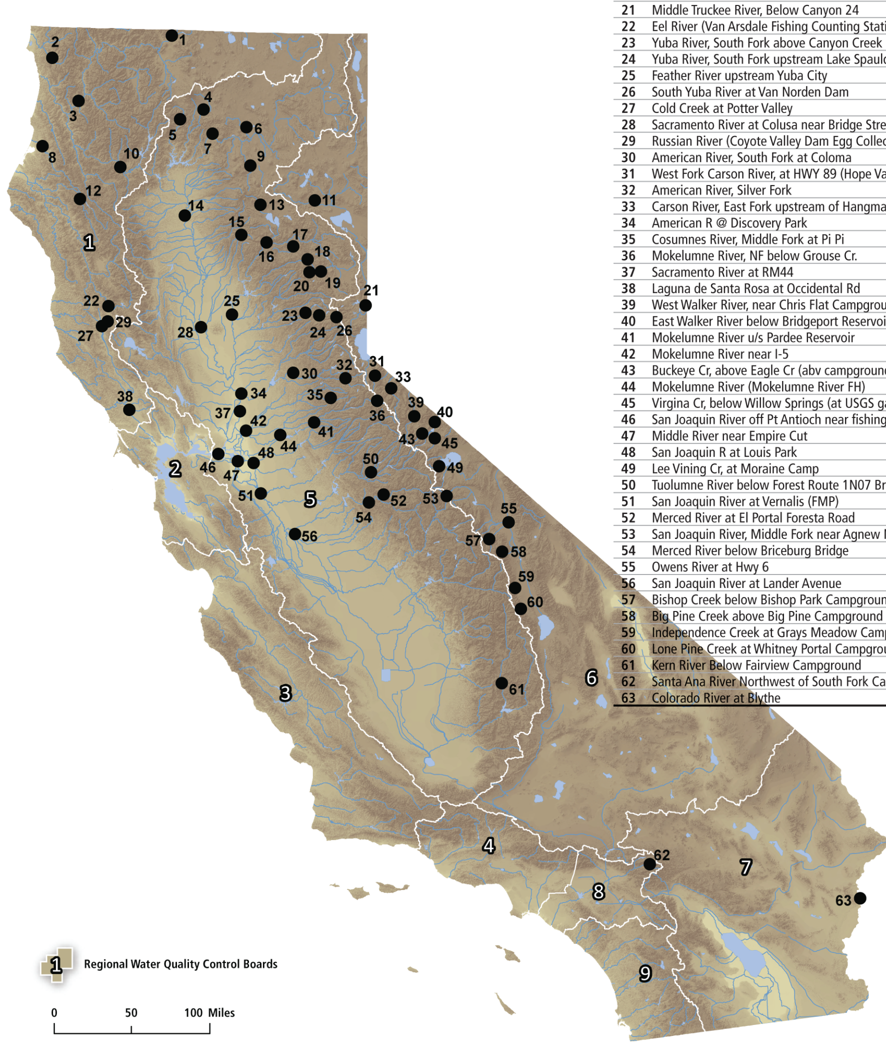

Figure 1. Locations sampled in the 2011 Rivers and Streams Survey, and level of concern for methylmercury and PCBs. The small proportion of locations in southern California reflects the Stienstra ratings and the lower amount and quality of fishing activity in this arid region.

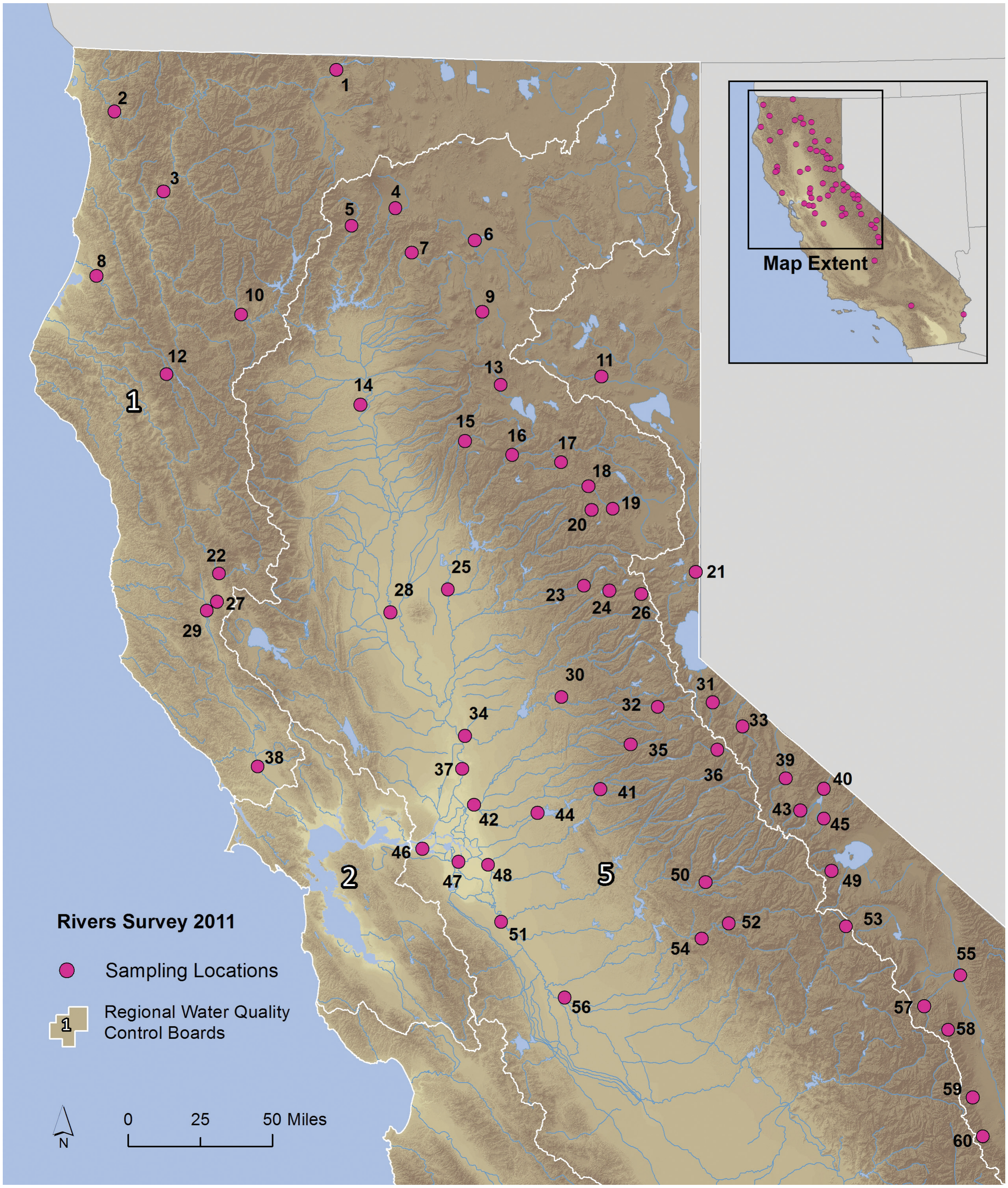

Figure 2. Locations sampled in the 2011 Rivers and Streams Survey: Northern California.

TARGET SPECIES

Given the focus of the screening study on the fishing beneficial use, the species to be sampled were those that are commonly caught and consumed by anglers. Other factors considered include abundance, geographic distribution, and value as indicators for the contaminants of concern. The abundance and geographic distribution of species are factors that facilitate sample collection and assessment of spatial patterns in contamination. For example, largemouth bass is very common and widely distributed, and these factors contribute to making this an appropriate indicator species even though it is less popular for consumption than some other species.

The goal of this screening study was to determine whether popular fishing locations in California rivers and streams have unacceptably high concentrations of contaminants. Given this goal, the study focused on indicator species that tend to accumulate the highest concentrations of the contaminants of concern. Different contaminants tend to reach their highest concentrations in different species. Methylmercury biomagnifies primarily through its accumulation in muscle tissue, and top predators such as largemouth bass tend to have the highest concentrations. In contrast, the organic contaminants of concern biomagnify, but do so primarily through accumulation in lipid. Concentrations of organics are therefore also influenced by the lipid content of the species, with species that are higher in lipid having higher concentrations. Bottom-feeding species such as channel catfish and common carp tend to have the highest lipid concentrations in their muscle tissue, and therefore usually have the highest concentrations of organics. Selenium also biomagnifies, though to a lesser degree than methylmercury and the organochlorines, primarily through accumulation in muscle, but past monitoring in the San Joaquin Valley (Beckon et al. 2010) suggests that bottom-feeders accumulate slightly higher concentrations, perhaps an indication of a stronger association of selenium contamination with the benthic food web.

Consequently, this study targeted two indicator species at each location – a top predator (e.g., largemouth bass) as a mercury indicator and a high-lipid, bottom-feeding species (e.g., channel catfish, common carp) as an organics and selenium indicator. Another advantage of this approach is that it provides a characterization of both the pelagic and benthic food chains. These considerations led USEPA (2000) to recommend this two-species approach in their guidance document for monitoring in support of development of consumption advisories. Many of the river and stream sampling locations selected had only one abundant taxon: trout. In these cases, one trout species was sampled as an indicator for all the target analytes. This approach is practical, as it is not common to find multiple trout species in abundance at a single location, and cost-effective because fewer samples must be analyzed. If both rainbow and brown trout were present, brown trout were collected because they have the potential to have a higher trophic position and accumulate more methylmercury than rainbow trout.

Fish species are distributed unevenly across the state, with different assemblages in different regions (e.g., high Sierra Nevada, Sierra Nevada foothills, and Central Valley) and a variable distribution within each region (Moyle 2002). A list of primary and secondary target species was developed (Table 3 in the Sampling Plan [Bioaccumulation Oversight Group 2011]).

A list of the species collected in the Rivers and Streams Survey is provided in Table 1, along with information on the number of locations sampled, fish sizes, and how the fish were processed. Specific size ranges were targeted for each species, as shown in Table 4 of the Sampling Plan (BOG 2011).

Chemical analysis of trace organics is relatively expensive, and the management questions established for this survey can be addressed with good information on average concentrations, so a compositing strategy was employed for these chemicals, consistent with the approach taken for the previous surveys of lakes and the coast.

Chemical analysis of total mercury is much less expensive, and, consistent with the previous surveys, SWAMP stakeholders are interested in information pertaining to spatial variation among locations and trends over time. Consequently, the sampling design for the mercury indicator species (black bass, pikeminnow, and striped bass) included analysis of mercury in individual fish. These species have a high trophic position and a strong size:mercury relationship. The numbers and sizes targeted for these species provided the size range needed to support statistical comparisons that account for variation in size. In addition, the size range for black bass took the legal limit for these species (305 mm, or 12 inches) into account. The goal for black bass was to have a size distribution that encompassed the standard length (350 mm) to be used in regression-based analysis. This length is near the center of the distribution of legal-sized fish encountered in past studies (Davis et al. 2003, Melwani et al. 2007). Similarly, the size range for striped bass takes the legal limit for these species (457 mm, or 18 inches) into account, and provided the range of sizes needed to establish the length:mercury relationship within locations.

In many rivers and streams only trout species were available. Previous sampling of rainbow trout in the Bay-Delta watershed found low concentrations and a weak size:mercury relationship. Therefore, for these species the regression-based approach was not used. Mercury was generally analyzed in composites, with a specified size range targeted to control for size rather than a wide span to support a regression-based analysis. These trout were also analyzed as composites for organics. The size ranges established for trout are based on a combination of sizes prevalent in past sampling (Melwani et al. 2007) and the 75% rule recommended by USEPA (2000) for composite samples. In some cases larger trout were available and were analyzed as individuals.

Catfish, carp, bullhead, and sucker were the primary targets for organics and selenium. Samples for these species were analyzed as composites. Methylmercury was expected to be highest in the pelagic predators, but concentrations were also expected to be above thresholds for concern in the bottom-feeders, so mercury was analyzed in the bottom-feeder composites as well. The size ranges for these species were based on a combination of sizes prevalent in past sampling (Melwani et al. 2007) and the 75% rule recommended by USEPA (2000) for composite samples.

Table 1
Scientific and common names of fish species collected, the number of locations in which they were sampled, their minimum, median, and maximum total lengths (mm), and whether they were analyzed as composites or individuals. Species marked as "analyzed for individuals" were analyzed as individuals for mercury only.

Species Name	Common Name	Total Number of Locations Sampled	Number of Fish	Composites - Number of Locations	Composites - Number of Samples	Individuals - Number of Locations	Individuals - Number of Samples	Min Length (mm)	Median Length (mm)	Max Length (mm)	Analyzed as Composites	Analyzed as Individuals
Ameiurus catus	White Catfish	1	5	1	1			309	317	403	x	
Catostomus occidentalis	Sacramento Sucker	10	47	9	9	1	2	130	451	626	x	x
Cyprinus carpio	Common Carp	6	30	6	6			376	545	879	x	
Hesperoleucus symmetricus	California Roach	1	4	1	1			125	128	152	x	
Ictalurus punctatus	Channel Catfish	1	1			1	1	125	125	125		x
Micropterus dolomieu	Smallmouth Bass	2	20	2	2	2	20	187	246	420	x	x
Micropterus salmoides	Largemouth Bass	10	105	9	9	10	105	189	328	580	x	x
Morone saxatilis	Striped Bass	2	22	2	2	2	22	237	528	1074	x	x
Onchorhyncus mykiss gairdneri	Steelhead Rainbow Trout	3	15	3	3			485	689	779	x	
Oncorhynchus mykiss	Rainbow Trout	40	225	37	37	15	103	130	260	461	x	x
Oncorhynchus tshawytscha	Chinook Salmon	3	15	3	3			606	632	855	x	
Orthodon microlepidotus	Sacramento Blackfish	1	6	1	1	1	6	272	309	343	x	x
Perca flavescens	Yellow Perch	1	4	1	1			128	130	165	x	
Ptychocheilus grandis	Sacramento Pikeminnow	2	12	2	2	2	12	136	273	435	x	x
Salmo trutta	Brown Trout	11	40	8	8	3	5	114	188	264	x	x
Salvelinus fontinalis	Brook Trout	4	17	3	3	1	2	161	192	240	x	x

Interactive statewide maps showing the locations sampled and results for each species can be obtained from the My Water Quality portal: http://www.waterboards.ca.gov/mywaterquality

SAMPLE PROCESSING

Dissection and compositing of muscle tissue samples were performed following USEPA guidance (USEPA 2000). Detailed information on target size ranges, compositing, and other sample processing procedures is presented in the Sampling Plan (Bioaccumulation Oversight Group 2011).

Composites were created based on the 75% rule recommended by USEPA (2000). Composites generally consisted of equal masses of tissue from five fish, as recommended by USEPA (2000).

In general, fish had the skin dissected off, and only the fillet muscle tissue was used for analysis. This is inconsistent with the guidance of USEPA (2000) that recommends that fish with scales have the scales removed and be processed with skin on, and skin is only removed from scaleless fish (e.g., catfish). Skin removal has been consistently used in California monitoring. Doing all preparation skin-off yielded more homogeneous samples, better precision for all chemicals, and a better measure of mercury concentrations, which are our largest concern. The analysis of axial fillets without skin was also advised by a bi-national workgroup concerning the monitoring and analysis of mercury in fish (Wiener et al. 2007).

CHEMICAL ANALYSIS

All tissue concentrations in this report are expressed on a wet weight basis. Analytes were selected for inclusion in the study based on their likelihood of exceeding thresholds of concern and on the availability of thresholds specifically developed for California waters.

Mercury and Selenium

In most cases, nearly all (>95%) of the mercury present in fish fillets and in whole fish is methylmercury (Wiener et al. 2007, Greenfield and Jahn 2010). Consequently, monitoring programs usually analyze total mercury as a proxy for methylmercury, as was done in this study. USEPA (2000) recommends this approach, and the conservative assumption be made that all mercury is present as methylmercury to be most protective of human health.

Total mercury and selenium in all samples were measured by Moss Landing Marine Laboratory (Moss Landing, CA). Detection limits for total mercury and all of the other analytes are presented in Table 2. Analytical methods for mercury and the other contaminants were described in the Sampling Plan (Bioaccumulation Oversight Group 2011). Mercury was analyzed according to EPA 7473, "Mercury in Solids and Solutions by Thermal Decomposition, Amalgamation, and Atomic Absorption Spectrophotometry" using a Direct Mercury Analyzer. Selenium was digested according to EPA 3052M, "Microwave Assisted Acid Digestion of Siliceous and Organically Based Matrices," modified, and analyzed according to EPA 200.8, "Determination of Trace Elements in Waters and Wastes by Inductively Coupled Plasma-Mass Spectrometry." Mercury and selenium results were detected and quantified (reportable) for 100% and 69% of the samples analyzed, respectively (Table 2).

Mercury analyses were performed on individual fish for selected species (Table 1). Selenium analyses were performed only on composite samples.

Table 2
Analytes included in the study, detection limits, number of observations, and frequencies of detection and reporting. Frequency of detection includes all results above detection limits. Frequency of reporting includes all results that were reportable (above the detection limit and passing all QA review). Units for the MDLs are ppm for mercury and selenium and ppb for the other organics (all on a wet weight basis).

Laboratory	Class	Analyte	Method Detection Limit	Number of Observations	Frequency of Detection (%)	Frequency of Reporting (%)	Frequency of Reporting (%)
DFG-WPCL	CHLORDANE	Chlordane, cis-	0.4	62	26	23	23
DFG-WPCL	CHLORDANE	Chlordane, trans-	0.45	62	21	18	18
DFG-WPCL	CHLORDANE	Nonachlor, cis-	0.31	62	5	5	5
DFG-WPCL	CHLORDANE	Nonachlor, trans-	0.19	62	63	63	63
DFG-WPCL	CHLORDANE	Oxychlordane	0.47	62	3	3	3
DFG-WPCL	DDT	DDD(o,p')	0.1	62	18	10	10
DFG-WPCL	DDT	DDD(p,p')	0.12	62	53	53	53
DFG-WPCL	DDT	DDE(o,p')	0.18	62	6	6	6
DFG-WPCL	DDT	DDE(p,p')	0.55	62	79	79	79
DFG-WPCL	DDT	DDT(o,p')	0.21	62	3	3	3
DFG-WPCL	DDT	DDT(p,p')	0.15	62	16	16	16
DFG-WPCL	DIELDRIN	Dieldrin	0.45	62	52	52	52
MPSL-DFG	MERCURY	Mercury	0.01	338	100	100	100
DFG-WPCL	BIOTOXIN	Anatoxin-A	5	20	0	0	0
DFG-WPCL	BIOTOXIN	Desmethyl-LR	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	Desmethyl-RR	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	Domoic acid	2	20	0	0	0
DFG-WPCL	BIOTOXIN	MCY-LA	0.5	20	0	0	0

Laboratory	Class	Analyte	Method Detection Limit	Number of Observations	Frequency of Detection (%)	Frequency of Reporting (%)	Frequency of Reporting (%)
DFG-WPCL	BIOTOXIN	MCY-LF	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	MCY-LR	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	MCY-LW	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	MCY-LY	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	MCY-RR	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	MCY-YR	0.5	20	0	0	0
DFG-WPCL	BIOTOXIN	Nodularin	5	20	0	0	0
DFG-WPCL	BIOTOXIN	Okadaic acid	1	20	0	0	0
DFG-WPCL	PCB	PCB 008	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 018	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 027	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 028	0.2	62	19	19	19
DFG-WPCL	PCB	PCB 029	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 031	0.2	62	2	2	2
DFG-WPCL	PCB	PCB 033	0.2	62	2	2	2
DFG-WPCL	PCB	PCB 044	0.2	62	31	31	31
DFG-WPCL	PCB	PCB 049	0.2	62	18	18	18
DFG-WPCL	PCB	PCB 052	0.2	62	61	40	40
DFG-WPCL	PCB	PCB 056	0.2	62	3	3	3
DFG-WPCL	PCB	PCB 060	0.2	62	2	2	2
DFG-WPCL	PCB	PCB 064	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 066	0.2	62	26	26	26
DFG-WPCL	PCB	PCB 070	0.3	62	23	23	23
DFG-WPCL	PCB	PCB 074	0.2	62	13	13	13
DFG-WPCL	PCB	PCB 077	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 087	0.3	62	18	18	18
DFG-WPCL	PCB	PCB 095	0.3	62	40	29	29
DFG-WPCL	PCB	PCB 097	0.2	62	18	18	18
DFG-WPCL	PCB	PCB 099	0.2	62	44	44	44
DFG-WPCL	PCB	PCB 101	0.3	62	69	55	55
DFG-WPCL	PCB	PCB 105	0.2	62	32	32	32
DFG-WPCL	PCB	PCB 110	0.3	62	71	50	50
DFG-WPCL	PCB	PCB 114	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 118	0.3	62	65	65	65

Laboratory	Class	Analyte	Method Detection Limit	Number of Observations	Frequency of Detection (%)	Frequency of Reporting (%)	Frequency of Reporting (%)
DFG-WPCL	PCB	PCB 126	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 128	0.2	62	15	15	15
DFG-WPCL	PCB	PCB 137	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 138	0.2	62	79	65	65
DFG-WPCL	PCB	PCB 141	0.2	62	10	10	10
DFG-WPCL	PCB	PCB 146	0.2	62	5	5	5
DFG-WPCL	PCB	PCB 149	0.2	62	56	56	56
DFG-WPCL	PCB	PCB 151	0.2	62	6	6	6
DFG-WPCL	PCB	PCB 153	0.2	62	84	84	84
DFG-WPCL	PCB	PCB 156	0.2	62	3	3	3
DFG-WPCL	PCB	PCB 157	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 158	0.2	62	5	5	5
DFG-WPCL	PCB	PCB 169	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 170	0.2	62	6	6	6
DFG-WPCL	PCB	PCB 174	0.2	62	6	6	6
DFG-WPCL	PCB	PCB 177	0.2	62	6	6	6
DFG-WPCL	PCB	PCB 180	0.2	62	29	29	29
DFG-WPCL	PCB	PCB 183	0.2	62	5	5	5
DFG-WPCL	PCB	PCB 187	0.2	62	23	23	23
DFG-WPCL	PCB	PCB 189	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 194	0.2	62	2	2	2
DFG-WPCL	PCB	PCB 195	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 198/199	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 200	0.2	62	0	0	0
DFG-WPCL	PCB	PCB 201	0.2	62	5	5	5
DFG-WPCL	PCB	PCB 203	0.2	62	6	6	6
DFG-WPCL	PCB	PCB 206	0.2	62	2	2	2
DFG-WPCL	PCB	PCB 209	0.2	62	0	0	0
MPSL-DFG	SELENIUM	Selenium	0.15	86	100	100	100

Organics

PCBs and legacy pesticides were analyzed by the California Department of Fish and Wildlife Water Pollution Control Laboratory (Rancho Cordova, CA). Organochlorine pesticides were analyzed according to EPA 8081AM, "Organochlorine Pesticides by Gas Chromatography." PCBs were analyzed according to EPA 8082M, "Polychlorinated Biphenyls (PCBs) by Gas Chromatography."

PCBs are reported as the sum of 55 congeners (Table 2). Concentrations in many locations were near or below limits of detection (Table 2). The congeners contributing most to the sum of PCBs were reportable in 50-84% of the 62 samples analyzed for PCBs. The inclusion of many samples with low concentrations caused the somewhat low percentages of reportable results. Frequencies of detection and reporting were lower for the less abundant PCB congeners that have a smaller influence on sum of PCBs. For PCBs and all of the organics presented as "sums," the sums were calculated with values for samples with concentrations below the limit of detection set to zero.

DDTs are reported as the sum of six isomers (Table 2). Chlordanes are reported as the sum of five compounds (Table 2).

Organics analyses were performed only on composite samples.

QUALITY ASSURANCE

The samples were analyzed in multiple batches. Quality assurance analyses were performed for each batch as required by the Quality Assurance Program Plan (QAPP) for this Survey (Bonnema 2011).

Data that met all measurement quality objectives (MQOs) as specified in the QAPP are classified as "compliant" and considered usable without further evaluation. Data that failed to meet all program MQOs specified in the QAPP were classified as "qualified" but considered usable for the intended purpose. Data that were >2X MQO requirements or the result of blank contamination were classified as "rejected" and considered unusable. Data batches where results were not reported and therefore not validated were classified as "not applicable".

A detailed description of the quality assurance data for this Survey is provided in Appendix 1. There were 10,483 sample results for individual constituents including tissue composites and laboratory QA/QC samples. Of these:

- 6,875 (65.6%) were classified as "compliant"
- 2,801 (26.7%) were classified as "qualified"
- 168 (1.7 %) were classified as "estimated"
- 395 (3.77%) were classified as "screening"

- 65 (0.62%) were classified as "rejected"; and
- 179 (1.7%) were classified as "NA", since either the results were not reported due to high native concentrations and could not be validated or since age results were not verified but presented for informational purposes.

Classification of this dataset is summarized as follows:

- 65 results were classified as "rejected" and 11 results were classified as "qualified" due to blank contamination.
- 85 results were classified as "qualified" due to surrogate recovery exceedances presented in Table 2 (Appendix 1).
- 24 results were classified as "qualified" due to recovery exceedances presented in Tables 3 and 5 (Appendix 1).
- 7 results were classified as "qualified" due to the RPD exceedances presented in Table 3 (Appendix 1).
- All data presented in Tables 4 and 6 (Appendix 1) were classified as "qualified" due to insufficient QC samples performed.
- 2,119 results were classified as "qualified" due to holding time exceedances.
- 168 results were classified as "estimated" due to holding time exceedances.
- 395 results were classified as "screening" since QC standards are not available and compound identification was based on retention time, molecular weights, qualifier ions, and ion ratios.

All data with the exception of the 65 rejected results were considered usable for the intended purpose. A 99% completeness level was attained which met the 90% project completeness goal specified in the QAPP (Bonnema 2011).

STATISTICAL METHODS

In general, simple descriptive statistics are presented in the text, tables, and figures. For methylmercury, analysis of individual samples for two species (largemouth bass and smallmouth bass) provided a foundation for more sophisticated procedures to adjust for the relationship with fish size (Table 1, Figure 3). Rainbow trout were also analyzed as individuals at many locations, but did not accumulate much methylmercury or exhibit a clear relationship with size (Table 1, Figure 4).

Since methylmercury concentrations in fish often are correlated with fish size, especially in larger predatory species, analysis of covariance is a valuable approach for assessing spatial and temporal patterns in a manner that reduces the influence of differences in size on the patterns. To perform the analysis of covariance for methylmercury concentrations in largemouth bass and smallmouth bass, results were calculated for a 350 mm fish, using the residuals of a length versus log10(Hg) relationship. This size has been used for standardization in past studies (e.g., Davis et al. 2008, Melwani et al. 2009), and represents the middle of the distribution of legal-sized (> 305 mm, or 12 inches) fish that

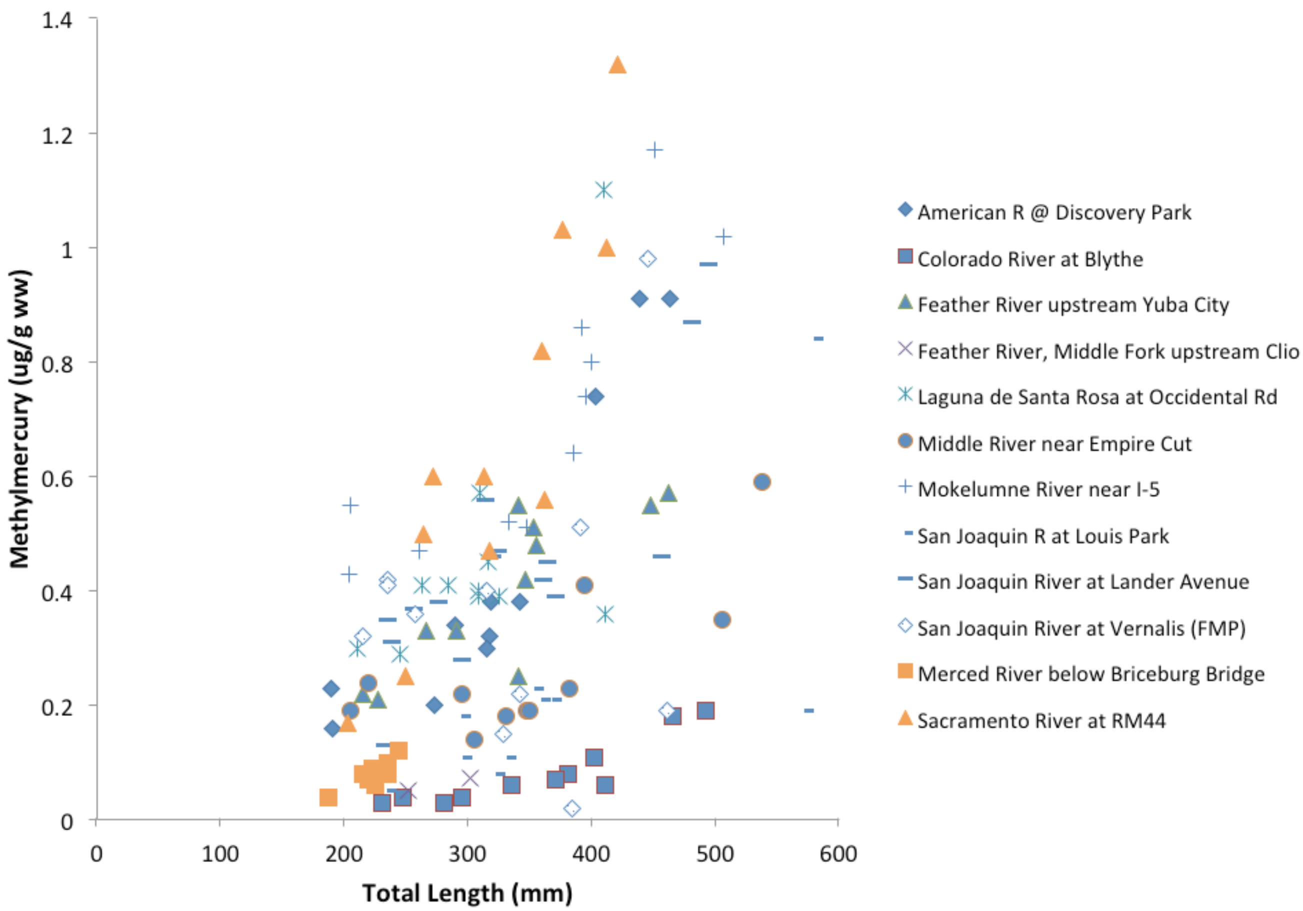

Figure 3. Methylmercury (ppm wet weight) versus length (mm) for black bass species. Blue symbols for largemouth bass, orange symbols for smallmouth bass.

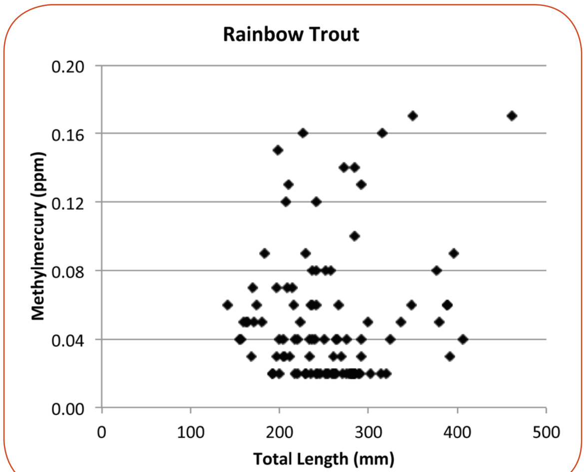

Figure 4. Methylmercury (ppm wet weight) versus length (mm) for rainbow trout.

are commonly caught. Methylmercury concentrations were log10-transformed to normalize the regression residuals. The analysis was done for the largemouth and smallmouth bass combined, excluding the three stations Merced River below Briceburg Bridge, Feather River Middle Fork upstream Clio, and San Joaquin River at Vernalis (due to problems at these locations with sample size, size range, or the length:methylmercury relationship), as follows. A centered length was created by subtracting the overall mean (for the entire multi-location dataset) length from the length of each individual sample. An analysis of covariance (ANCOVA) was done using log10(Hg) as the response variable, centered length as the regressor (covariate), and station as a categorical factor to assess if the regression between centered length and log10(Hg) were comparable between stations. A non-significant interaction between the length and station suggested the slope of the regression between centered length and log10(Hg) was similar for the stations (Hebert and Keenleyside 1995). The interaction term for the combined species ($F = 2.67$, $p = 0.012$) was significant; therefore, individual station regressions, instead of a common regression slope, were used to estimate concentrations for standard-sized fish (Hebert and Keenleyside 1995).

Size-standardized concentrations were estimated using the formula:

Size-standardized concentration = intercept+(centered length for 350 mm individual * slope)+residual

and then back-transformed to original units by 10 to the power of X, where X = the size-standardized concentration. Location means based on these size-standardized concentrations are presented in the summary figures, the appendix tables, and the "Safe to Eat" Portal.

ASSESSMENT THRESHOLDS

This report compares fish tissue concentrations to two types of thresholds of concern for contaminants in sport fish that were developed by OEHHA (Klasing and Brodberg 2008): Fish Contaminant Goals (FCGs) and Advisory Tissue Levels (ATLs) (Table 3).

Table 3
Thresholds for concern based on an assessment of human health risk by OEHHA (Klasing and Brodberg, 2008). All values given in ng/g (ppb) wet weight. The lowest available threshold for each pollutant is in bold font. One serving is defined as 8 ounces (227 g) prior to cooking. The FCG and ATLs for mercury are for the most sensitive population (i.e., women aged 18 to 45 years and children aged 1 to 17 years).

Pollutant	Fish Contaminant Goal	Advisory Tissue Level (2 servings/week)	Advisory Tissue Level (1 serving/week)	Advisory Tissue Level (No Consumption)
Chlordanes	**5.6**	190	280	560
DDTs	**21**	520	1000	2100
Dieldrin	**0.46**	15	23	46
Mercury	220	**70**	150	440
PCBs	**3.6**	21	42	120
Selenium	7400	**2500**	4900	15000
PBDEs	310	100	210	630

FCGs provide a starting point for OEHHA to assist other agencies that wish to develop fish tissue-based criteria with a goal toward pollution mitigation or elimination. As described by Klasing and Brodberg (2008), FCGs are "estimates of contaminant levels in fish that pose no significant health risk to humans consuming sport fish at a standard consumption rate of one serving per week (or eight ounces [before cooking] per week, or 32 g/day), prior to cooking, over a lifetime.... FCGs prevent consumers from being exposed to more than the daily reference dose for non-carcinogens or to a risk level greater than 1x10-6 for carcinogens (not more than one additional cancer case in a population of 1,000,000 people consuming fish at the given consumption rate over a lifetime). FCGs are based solely on public health considerations without regard to economic considerations, technical feasibility, or the counterbalancing benefits of fish consumption." For organic contaminants (with the exception of PBDEs), FCGs are lower than ATLs.

ATLs were developed by OEHHA as a starting point in the process to develop consumption advice. ATLs, as well as advisories and safe eating guidelines based on them, balance the risks and benefits from fish consumption. As described by Klasing and Brodberg (2008), ATLs, "while still conferring no significant health risk to individuals consuming sport fish in the quantities shown over a lifetime, were developed with the recognition that there are unique health benefits associated with fish consumption and that the advisory process should be expanded beyond a simple risk paradigm in order to best promote the overall health of the fish consumer. ATLs provide numbers of recommended fish servings that correspond to the range of contaminant concentrations found in fish and are used to provide consumption advice to prevent consumers from being exposed to more than the average daily reference dose for non-carcinogens or to a risk level greater than 1x10-4 for carcinogens (not more than one additional cancer case in a population of 10,000 people consuming fish at the given consumption rate over a lifetime). ATLs are designed to encourage consumption of fish that can be eaten in quantities likely to provide significant health benefits, while discouraging consumption of fish that, because of contaminant concentrations, should not be eaten or cannot be eaten in amounts recommended for improving overall health (eight ounces total, prior to cooking, per week). ATLs are but one component of a complex process of data evaluation and interpretation used by OEHHA in the assessment and communication of fish consumption risks. The nature of the contaminant data or omega-3 fatty acid concentrations in a given species in a water body, as well as risk communication needs, may alter strict application of ATLs when developing site-specific advisories. For example, OEHHA may recommend that consumers eat fish containing low levels of omega-3 fatty acids less often than the ATL table would suggest based solely on contaminant concentrations. OEHHA uses ATLs as a framework, along with best professional judgment, to provide fish consumption guidance on an ad hoc basis that best combines the needs for health protection and ease of communication for each site." For methylmercury and selenium, the 2 serving and 1 serving ATLs are lower than the FCGs.

Consistent with the description of ATLs above, the assessments presented in this report are not intended to represent consumption advice.

For methylmercury, results were also compared to a 0.3 ppm wet weight threshold that was used by the State and Regional Water Boards in the most recent round of 303(d) listing. This threshold is based on the current USEPA Clean Water Act Section 304(a) recommended criteria document that established a criterion of 0.3 ppm for methylmercury based on a protective human health default consumption rate of 17.5 grams per day (USEPA 2001).

SECTION 3 STATEWIDE ASSESSMENT FOR RIVERS AND STREAMS

In this one-year screening study, 568 fish representing 16 species were collected from 63 river and stream locations throughout California (Figures 1 and 2, Table 1). A concise tabulated summary of the data for each location is provided in Appendix 2. Data in a more detailed format for composites and averages are provided in Appendix 3, and for mercury analyses on individual fish in Appendix 4.

Excel files containing these tables are available from SFEI (contact Jay Davis, jay@sfei.org). All data collected for this study are maintained in the SWAMP database, which is managed by the data management team at Moss Landing Marine Laboratories (http://swamp.mpsl.mlml.calstate.edu/). The complete dataset includes QA data (quality control samples and blind duplicates) and additional ancillary information (specific location information, fish sex, weights, etc.). The complete dataset from this study will also be available on the web at www.ceden.org/. Finally, data from this study are available on the web through the California Water Quality Monitoring Council's "My Water Quality" portal (http://www.waterboards.ca.gov/mywaterquality/). The My Water Quality site is designed to present data on contaminants in fish and shellfish from SWAMP and other programs to the public in a nontechnical manner, and allows mapping and viewing of summary data from each fishing location.

METHYLMERCURY

Comparison to Thresholds

Methylmercury is the pollutant that poses the greatest potential health concern to consumers of fish caught in California rivers and streams.

OEHHA's no consumption advisory tissue level (ATL) of 0.44 ppm provides an upper bound threshold for assessment of methylmercury in California sport fish. This value represents a relatively high concentration above which frequent consumption might not be safe for the most sensitive fish consumers (children and women of childbearing age). OEHHA's lowest ATL for methylmercury of 0.07 ppm is a lower-bound threshold. Methylmercury concentrations below this level can be considered low.

Most of the 63 locations sampled (51%) had low concentrations of methylmercury (< 0.07 ppm) (Figures 5-7). This represents an estimate of the percentage of locations where frequent consumption of fish is likely to be safe with regard to methylmercury. Overall, 87% of the locations had average methylmercury concentrations below 0.44 ppm in the most contaminated species. Specific recommended consumption frequencies will be determined by OEHHA when sufficient data are available for this type of evaluation.

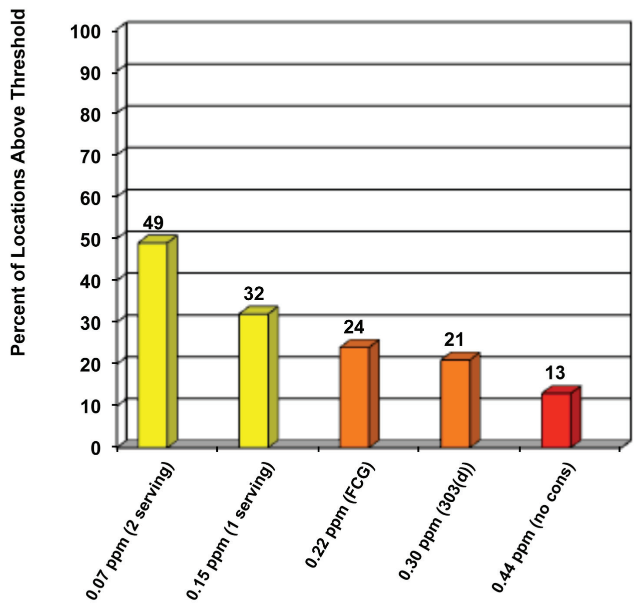

Figure 5. Percentages of river and stream sampling locations above various methylmercury thresholds.

A few locations, 8 of 63 (13%), were in the high contamination category, with an average for the most contaminated species exceeding 0.44 ppm (Figure 6). The 95% confidence interval for this estimate was 80-97% (Figure 7). Fifteen locations (24%) had a species above OEHHA's Fish Contaminant Goal of 0.22 ppm.

Regional variation in the occurrence of locations with high concentrations was observed. Most of the locations in the high contamination category were in the Delta and in nearby Delta tributaries ("Delta region") (Figure 6). The Delta region has been extensively monitored in past studies and the patterns observed in the present Survey are in close agreement with the patterns observed in 1998 by Davis et al. (2000), 1999 and 2000 by Davis et al. (2008), and from 2005-2007 by Melwani et al. (2009). All of these surveys show a persistent spatial pattern of high concentrations around the periphery of the Delta, with lower concentrations in the central Delta. The only other location with a concentration in the high category was the Laguna de Santa Rosa in Sonoma County, where largemouth bass had an estimated average of 0.52 ppm for a standard size of 350 mm. Common carp at this location also had a relatively high concentration of 0.35 ppm.

With the one exception of Laguna de Santa Rosa, river and stream locations outside of the Delta region all had low or moderate methylmercury contamination. At many of these locations, rainbow trout was the only target species that could be collected, and rainbow trout generally accumulate low methylmercury concentrations (discussed further below). Rainbow trout were collected at 40 locations, and exceeded 0.07 ppm at only six (15%) of those locations (Figure 8). Other species at these higher-elevation, cool water locations also tended to have low or moderate methylmercury contamination (Figure 6).

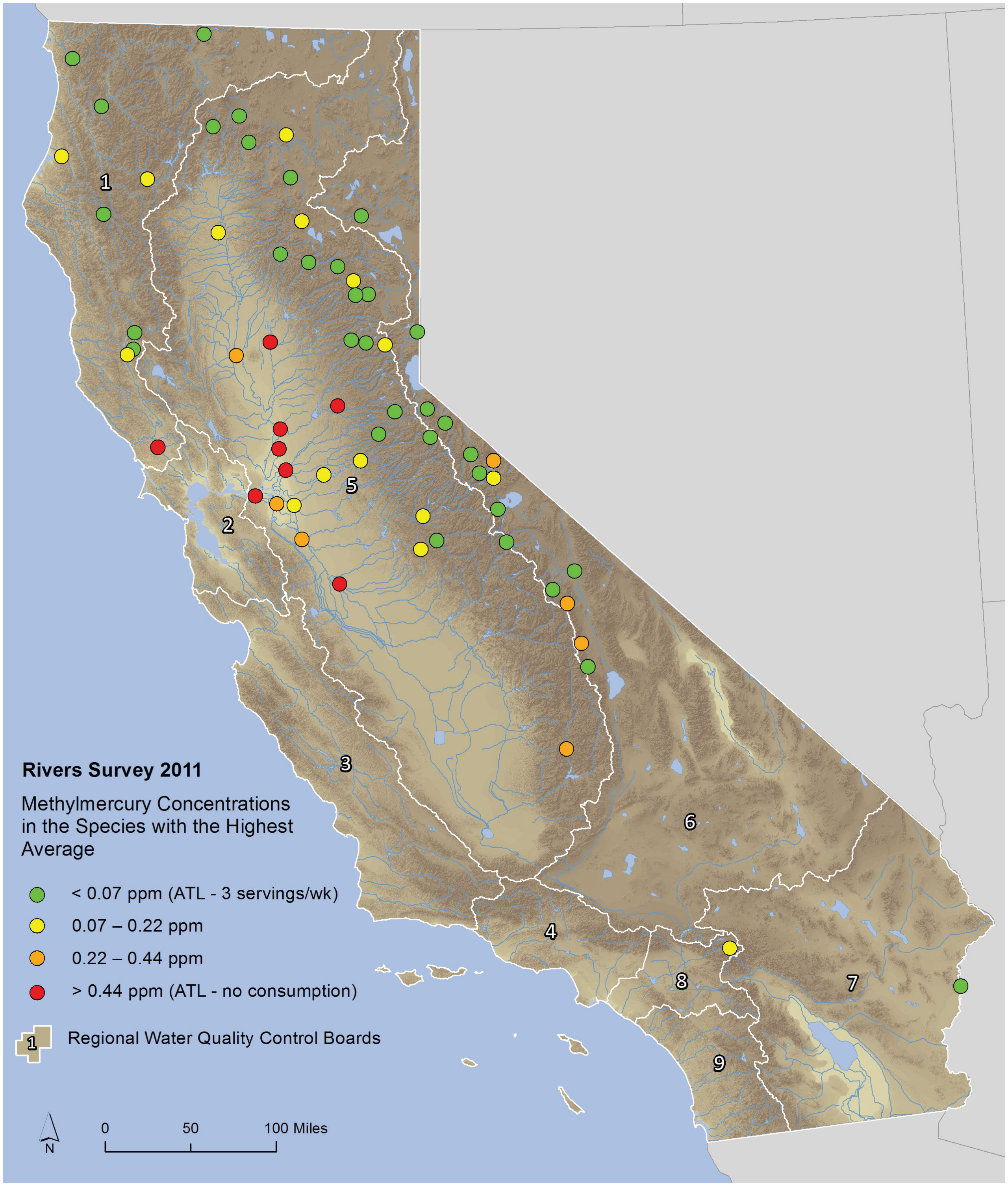

Figure 6. Spatial patterns in methylmercury concentrations among locations sampled in the 2011 Rivers and Streams Survey. Each point represents the highest average methylmercury concentration (ppm wet weight) among the species sampled at each location.

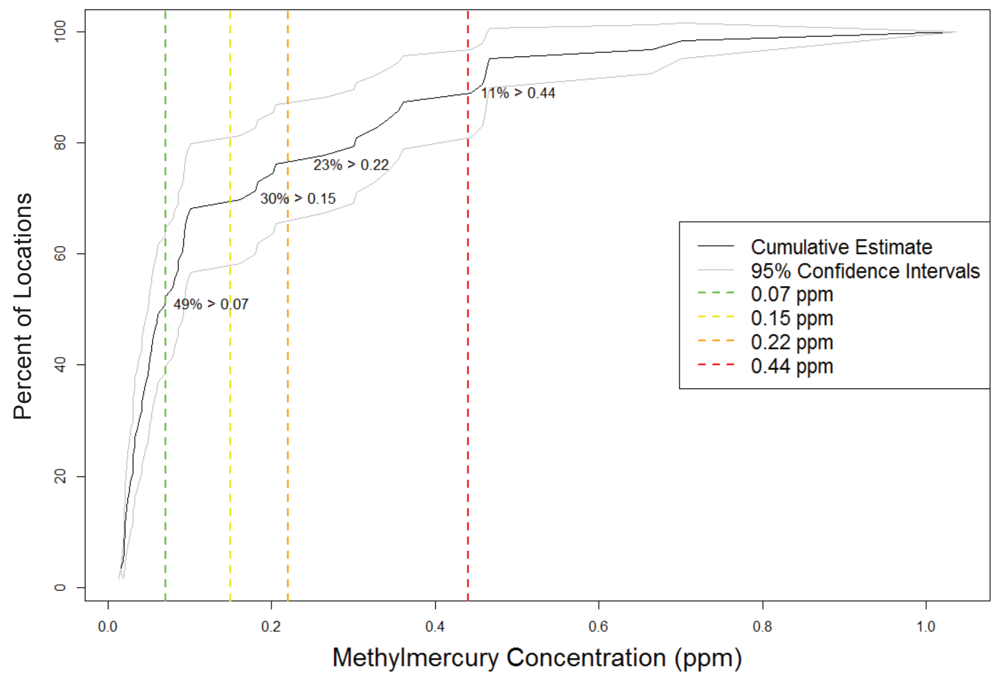

Figure 7. Cumulative distribution function (CDF) plot for methylmercury, shown as percent of locations sampled. Based on the highest species average concentration (ppm wet weight) for each location. Vertical lines are threshold values.

Another way to assess concentrations relative to the thresholds is to base the comparisons on the least contaminated species at each location. This provides an indication of the availability of fish species with low methylmercury. Using this metric, 40 of the 63 locations (63%) had at least one low methylmercury species (below 0.07 ppm).

Variation Among Species

A large amount of the variation observed in this dataset is due to differences among species in the degree to which they accumulate methylmercury. Relatively high methylmercury concentrations were observed in species that are high trophic level predators, including largemouth, smallmouth, and striped bass, and Sacramento pikeminnow (Figure 9). It should be noted, however, that for some of these species, the averages are based on small sample sizes and therefore are imprecise estimates. The statewide average concentrations in Sacramento pikeminnow (0.55 ppm) and smallmouth bass (0.73 ppm) exceeded OEHHA's no consumption ATL of 0.44 ppm, and the statewide averages for striped bass (0.41 ppm) and largemouth bass (0.34 ppm) were just below this threshold. Other lower trophic level species such as common carp, Sacramento blackfish, and Sacramento sucker had moderate methylmercury contamination.

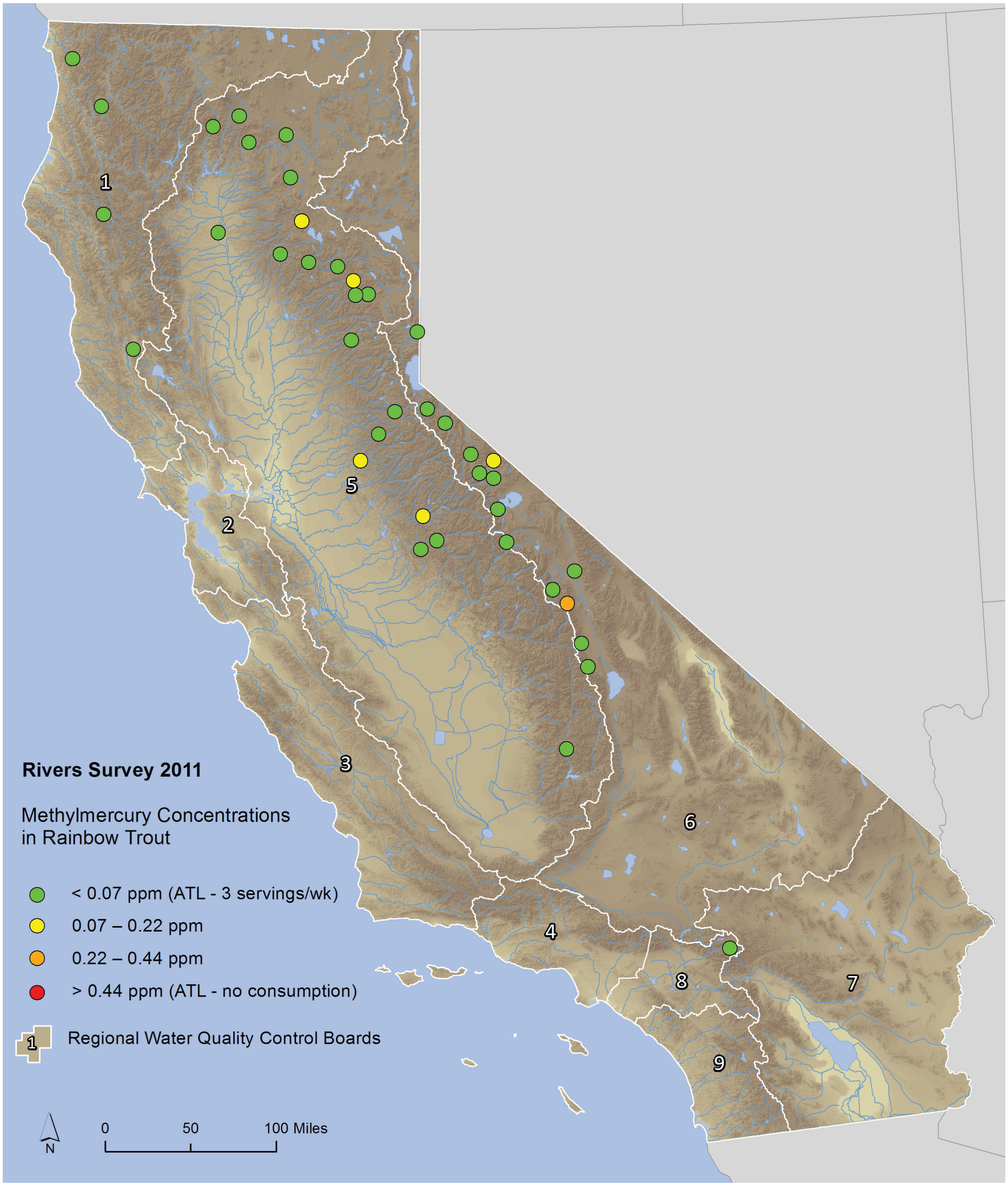

Figure 8. Spatial patterns in rainbow trout methylmercury concentrations among locations sampled in the 2011 Rivers and Streams Survey. Each point represents the highest average methylmercury concentration (ppm wet weight) among the species sampled at each location.

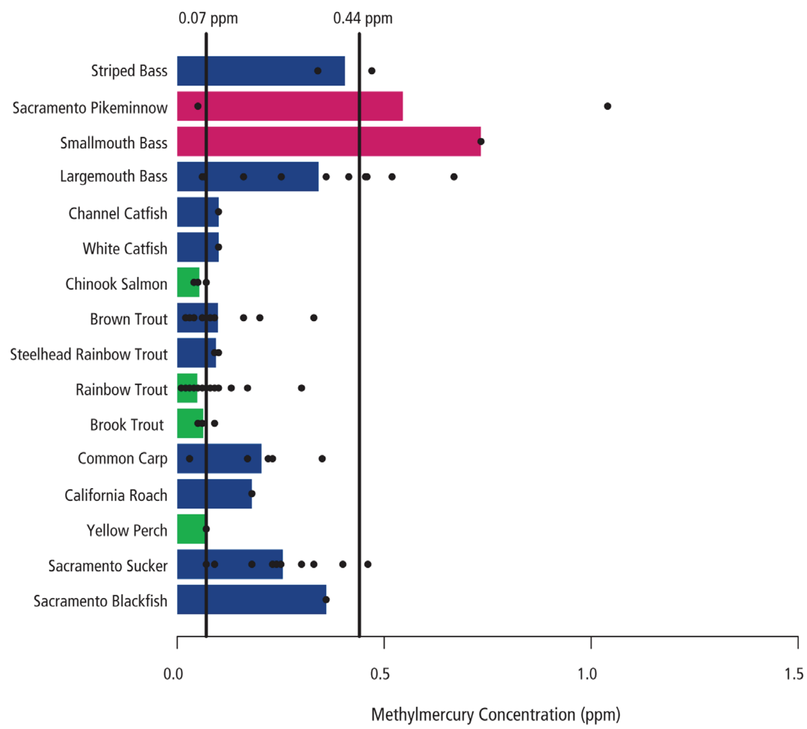

Figure 9. Methylmercury concentrations (ppm wet weight) in sport fish species in California rivers and streams, 2011. Dots show location means, bars show overall means.

Rainbow trout were sampled more extensively than any other species (40 locations), and generally had low concentrations of methylmercury, with a statewide average (0.05 ppm) below the lowest OEHHA threshold (the 0.07 ppm two serving ATL). Limited sampling of other trout species also yielded low average concentrations: 0.10 ppm in brown trout, 0.09 ppm in steelhead rainbow trout, and 0.06 ppm in brook trout. Trout generally occupy a lower trophic position, usually feeding on invertebrates, and accumulate lower concentrations of methylmercury and other pollutants. Another factor that likely contributes to lower observed concentrations in trout is that, in many locations, recently planted hatchery fish are part of the catch. A previous study found that hatchery trout consistently had very low concentrations of methylmercury (rainbow trout from four hatcheries all had less than 0.023 ppm – Grenier et al. 2007). Steelhead rainbow trout collected at three fish hatcheries had concentrations just above 0.07 ppm – none had an average concentration greater than 0.10 ppm.

Other trout species were sampled at a few locations and generally had low concentrations. Four locations with brook trout averaged 0.06 ppm, with three below 0.07 ppm; 11 locations with brown trout averaged 0.10 ppm, with six below 0.07 ppm.

Chinook salmon returning to spawn were sampled at three hatcheries and each had a concentration at or below 0.07 ppm.

Spatial Patterns

This dataset provides little opportunity for a more rigorous analysis of spatial variation than that already presented in the "Comparison to Thresholds" section above.

The most widely sampled species, rainbow trout, accumulated uniformly low concentrations, did not exhibit a correlation of concentration with size, and the four locations with moderate contamination were scattered widely along the Sierra Nevada (Figure 8).

Largemouth bass were analyzed as individual fish to support a more rigorous analysis of spatial and temporal trends based on size-standardized concentrations, but were collected at a limited number of locations (10), mostly in the Delta region (seven of the 10 locations). One of the non-Delta locations - Feather River upstream of Clio – yielded only two fish, so a size-standardized estimate could not be generated. One of the Delta locations (San Joaquin River at Vernalis) did not exhibit a correlation of concentration versus size, so a size-standardized estimate was also not generated for this location. The Merced River at Briceburg was excluded because only sub-legal sized smallmouth were collected. Size-standardized estimates were generated for the other eight largemouth locations and one smallmouth location (Figure 10). As mentioned previously, the Laguna de Santa Rosa (a non-Delta location) had a high concentration (0.52 ppm). Another non-Delta location – Colorado River at Blythe in southern California on the Arizona border – had a low concentration (0.06 ppm). Within the Delta region, the spatial pattern observed at the seven locations sampled reinforced the results of previous surveys going back to 1998 (Davis et al. 2000, Davis et al. 2008, Melwani et al. 2009), with high concentrations around the edges of the Delta and low concentrations in the central Delta.

In spite of the limitations of the dataset with respect to rigorous statistical analysis, the general pattern observed in this Survey–a prevalence of high concentrations in the Delta region and low to moderate concentrations in other regions–is consistent with the results of past monitoring and likely an accurate characterization of the condition of California rivers and streams.

Temporal Trends

Few data are available to support a statistical assessment of long-term trends in methylmercury concentrations in sport fish in California rivers and streams. Although a fairly extensive dataset exists from sampling in the 1970s, 1980s, and 1990s (Davis et al. 2007), monitoring over that period generally was very inconsistent in terms of species collected, size ranges, and locations; had very little replication; and established very few time series. Methods and consistency improved in the late 1990s, with time series initiated by the Sacramento River Watershed Program for a handful of sites on the lower Sacramento River, more intensive and statistically robust sampling from 1999-2000 and 2005-2007 funded by CalFed (Davis et al. 2008, Melwani et al. 2009), and now the present survey in 2011.

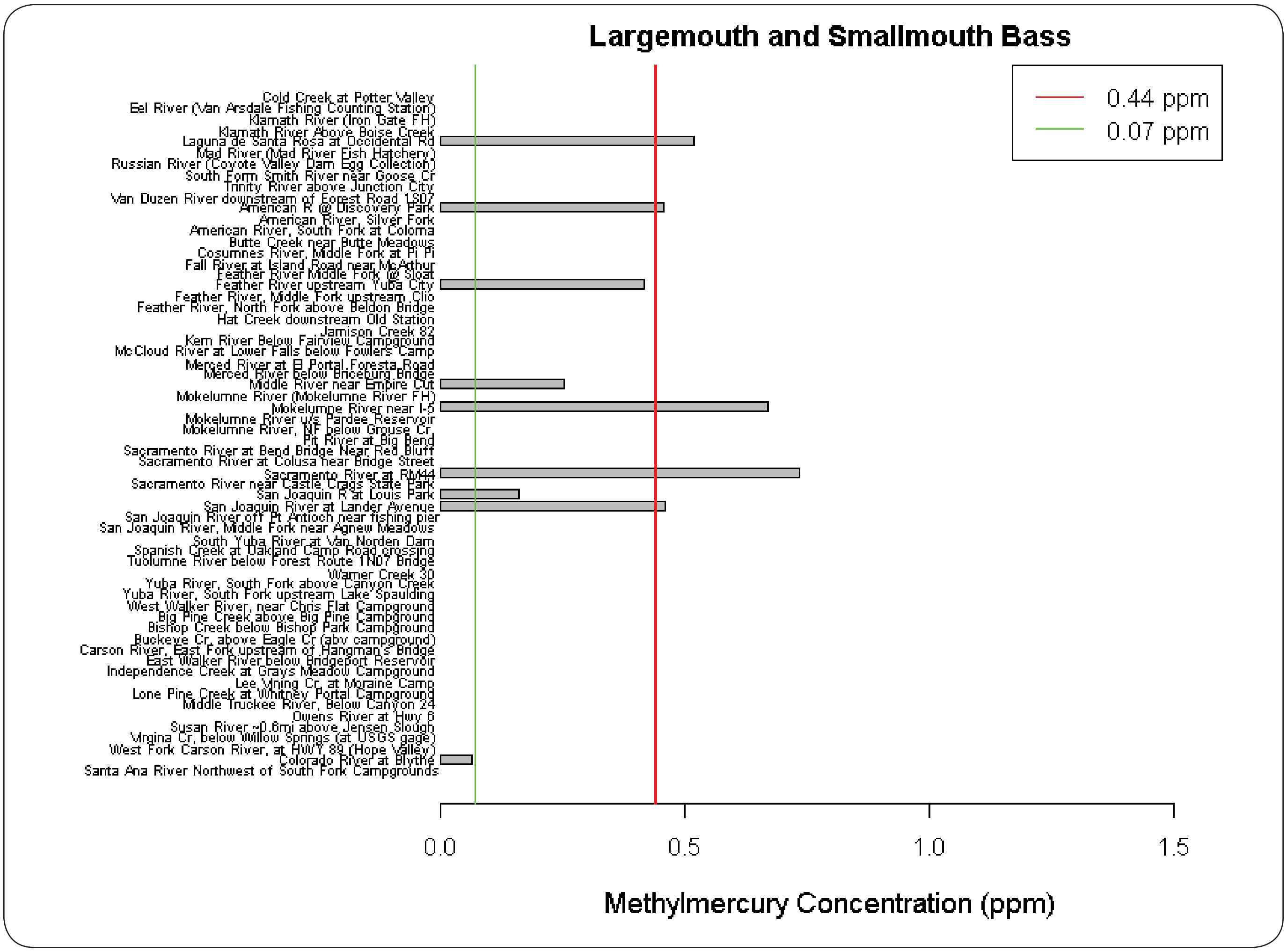

Figure 10. Length-adjusted methylmercury concentrations (ppm wet weight) in black bass. Concentrations estimated for a 350 mm fish through ANCOVA (see Methods for description). Sacramento River at RM44 value is for smallmouth bass; all others are largemouth bass.

Methylmercury concentrations at locations with repeated measurements of estimated concentrations in 350 mm bass are shown in Figure 11. For three of these "locations", data for nearby (within approximately one mile) stations were pooled. These time series generally show consistent concentrations over time, with relatively high concentrations at the sites around the northern periphery of the Delta (ranging between approximately 0.60 and 0.80 ppm), and lower concentrations at the locations in the Central Delta (ranging between approximately 0.20 and 0.30 ppm).

While these represent the best time series that are currently available, they are far from ideal due to inconsistencies in sampling location, sample sizes, size ranges, and species. Time series based on repeated, directly comparable measurements are needed for an accurate characterization of long-term trends. A lack of rigorous trend monitoring is an important information gap for methylmercury and other contaminants in California rivers and streams.

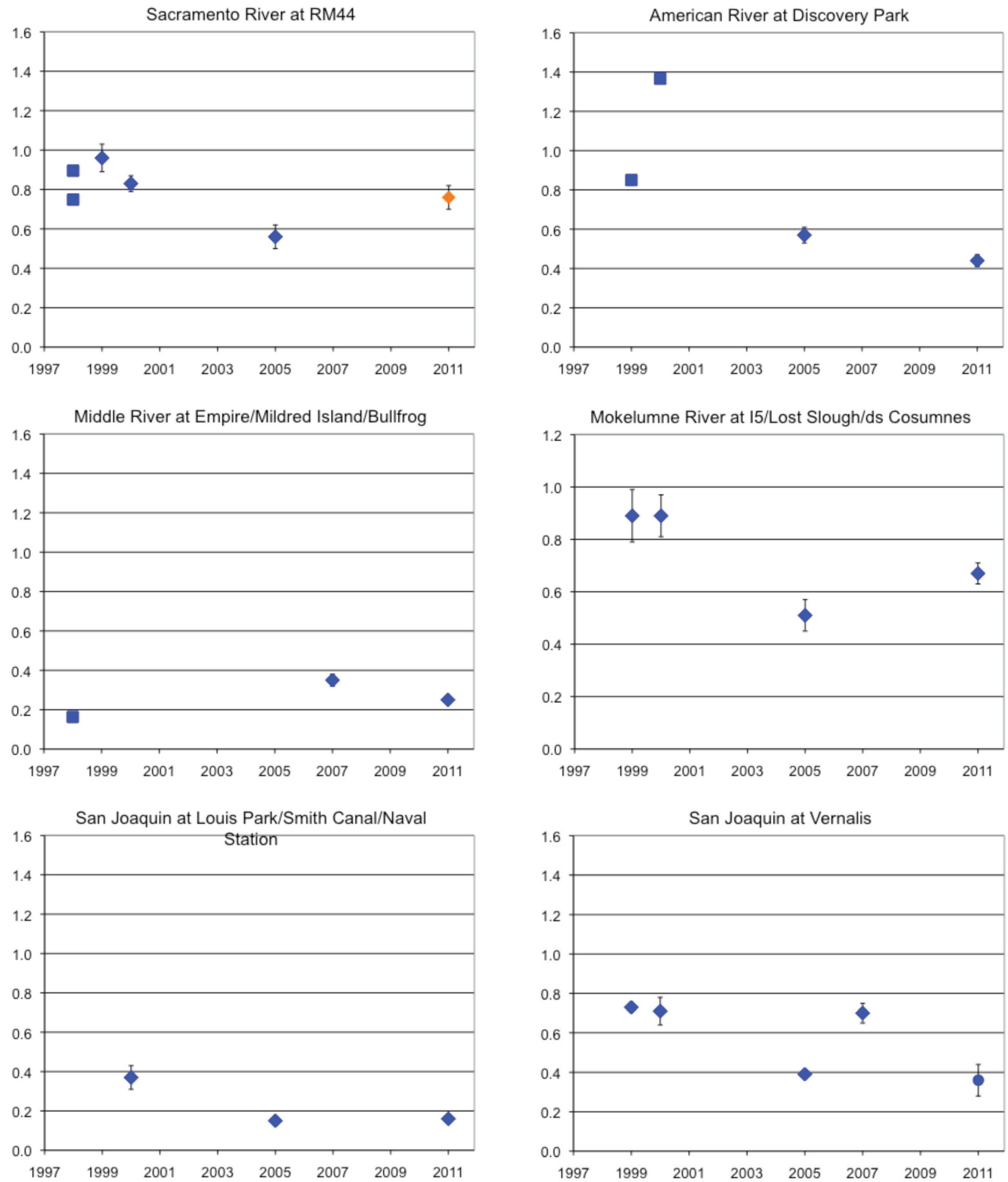

Figure 11.Methylmercury concentrations at trend sites. Largemouth bass shown in blue, smallmouth bass in orange. Diamonds represent averages based on ANCOVA generated estimates for a standard size of 350 mm. Squares represent composite samples. Circles represent simple averages for cases where no length correlation was observed.

OTHER CONTAMINANTS WITH THRESHOLDS

OEHHA (Klasing and Brodberg 2008) has developed thresholds for five other contaminants that were analyzed in this survey: dieldrin, PCBs, DDTs, chlordanes, and selenium. Concentrations of these contaminants did not exceed any of the no consumption ATLs, and rarely exceeded any ATL. The organic contaminants, however, did frequently exceed the FCGs.

Results for these contaminants are briefly summarized below.

Dieldrin

The maximum species averages for dieldrin were below the lowest threshold (the 0.46 ppb FCG) in 31 (52%) of the 60 locations sampled for organics (Figure 12). The remaining 29 locations fell between the FCG and the next lowest threshold (the 15 ppb 2-serving ATL). The highest concentration measured was 1.7 ppb in a common carp composite from the Laguna de Santa Rosa. Six locations had concentrations above 1 ppb: four of these were in the Delta (Sacramento sucker and common carp), one was the Laguna de Santa Rosa, and one was in the northern Sierra (Feather River, Middle Fork upstream of Clio – rainbow trout).

PCBs

PCBs had the second highest degree of contamination in the Lakes Survey and the Coast Survey, but were the third highest in this Survey. The maximum species averages for PCBs were below the lowest threshold (the 3.6 ppb FCG) in 41 (68%) of the 60 locations sampled (Figure 13). The remaining 19 locations fell between the FCG and the 42 ppb 1-serving ATL. Only two locations were above the 21 ppb 2-serving ATL. The highest concentration measured was 34 ppb in the common carp sample from Laguna de Santa Rosa. Only two other locations had concentrations at or above 20 ppb: the Mokelumne River upstream of Pardee Reservoir (21 ppb in rainbow trout) and Sacramento River at River Mile 44 (20 ppb in Sacramento sucker). The Delta had a relatively large proportion of the samples with the highest concentrations.

DDTs

The maximum species averages for DDTs were below the lowest threshold (the 21 ppb FCG) in 57 (95%) of the 60 locations sampled (Figure 14). Three locations (5%) fell between the FCG and the next lowest threshold (the 520 ppb 2-serving ATL). By far, the highest concentration measured was 289 ppb in the common carp composite from the Laguna de Santa Rosa. The other two locations with concentrations above 21 ppb were in the Delta: 39 ppb in Sacramento sucker from Sacramento River at River Mile 44, and 31 ppb in Sacramento sucker from the Mokelumne River near I-5.

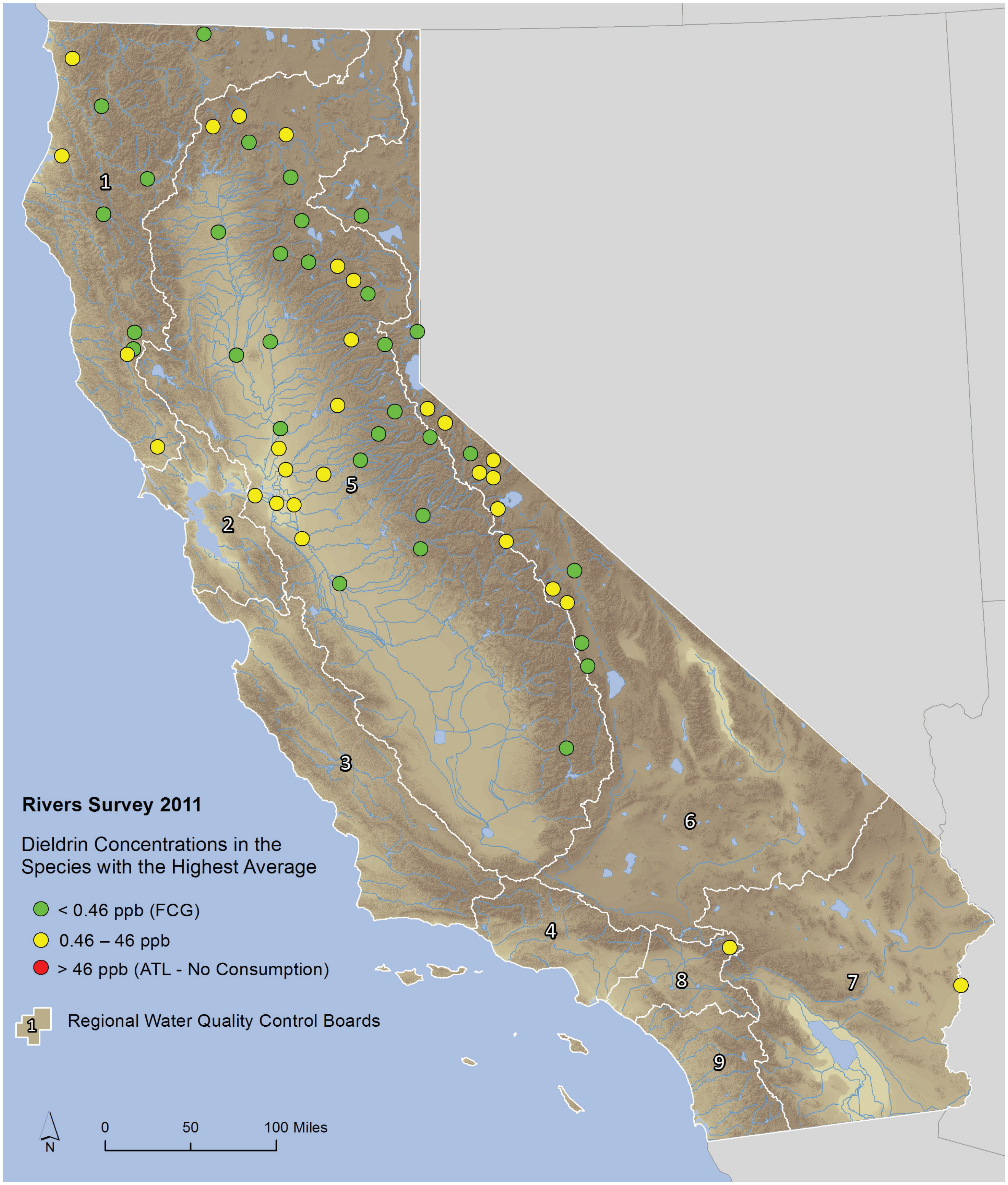

Figure 12. Spatial patterns in dieldrin concentrations among locations sampled in the 2011 Rivers and Streams Survey. Each point represents the highest average concentration among the species sampled at each location.

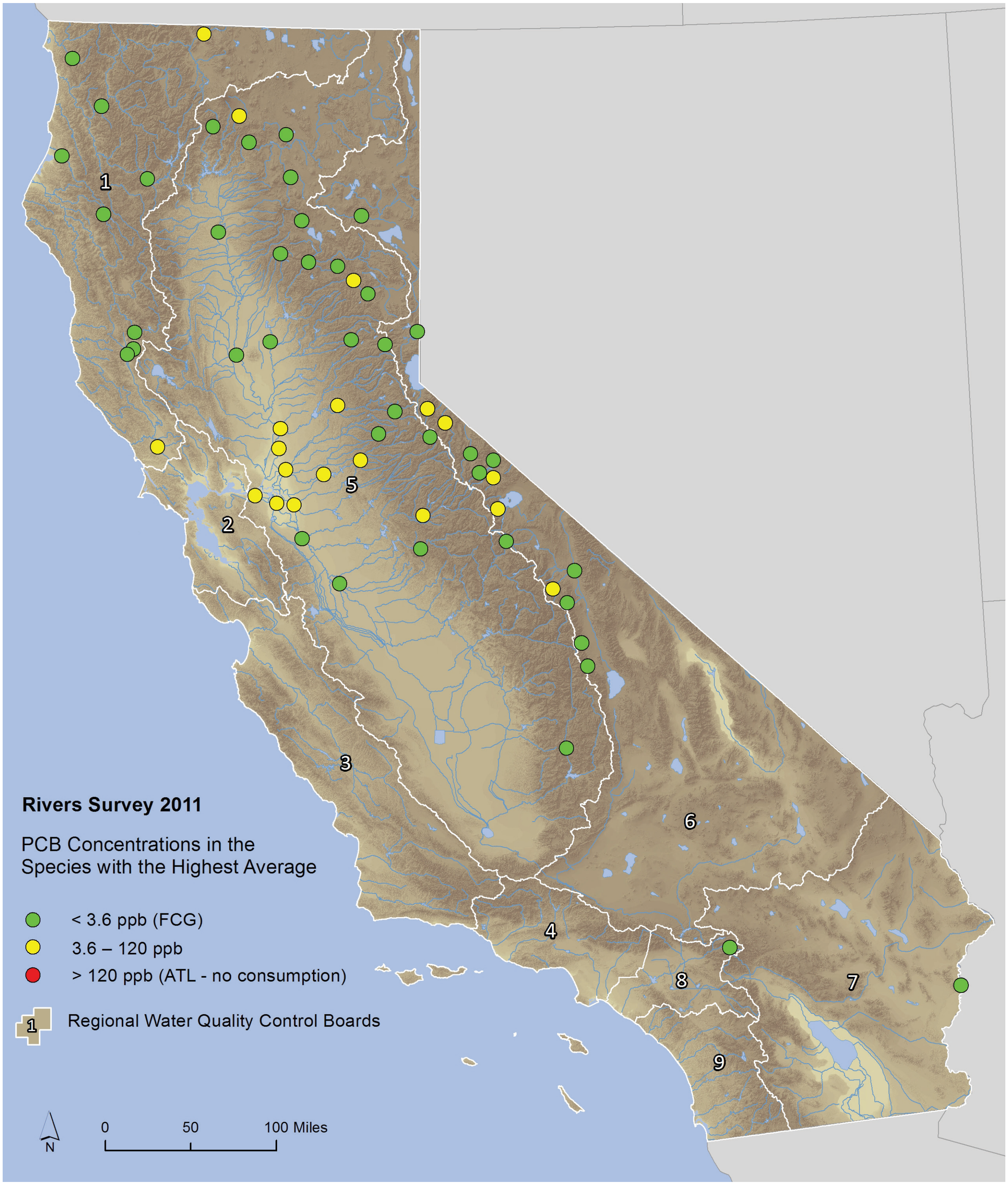

Figure 13. Spatial patterns in PCB concentrations among locations sampled in the 2011 Rivers and Streams Survey. Each point represents the highest average concentration among the species sampled at each location.

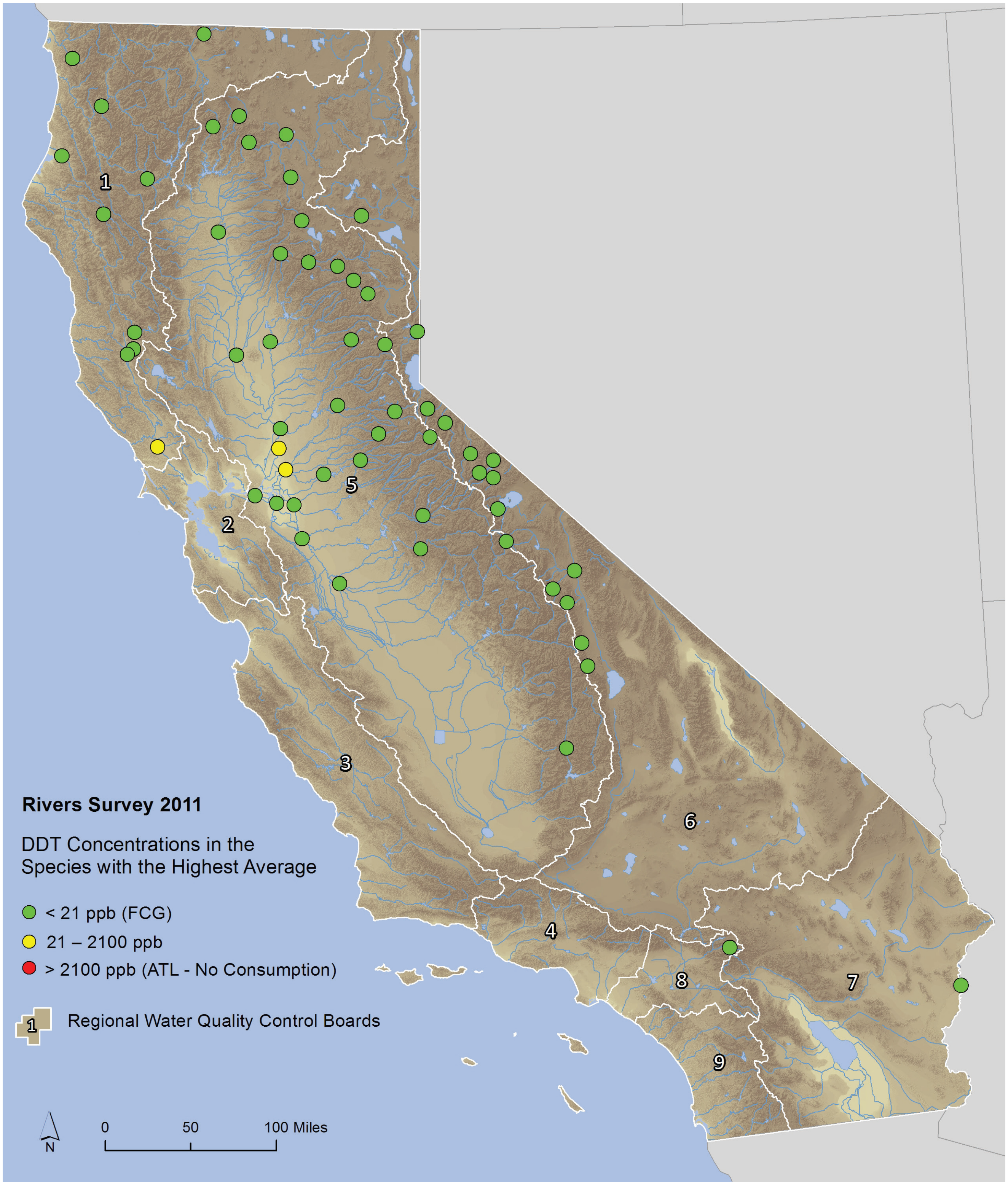

Figure 14. Spatial patterns in DDT concentrations among locations sampled in the 2011 Rivers and Streams Survey. Each point represents the highest average concentration among the species sampled at each location.

Chlordanes

The maximum species averages for chlordanes were below the lowest threshold (the 5.6 ppb FCG) in 59 (98%) of the 60 locations sampled (Figure 15). The one location with a concentration above 5.6 ppb was the common carp sample from the Laguna de Santa Rosa (10 ppb).

Selenium

The maximum species averages for selenium were below the lowest threshold (the 2.5 ppm 2 serving ATL) in 59 (98%) of the 60 locations sampled (map not shown). The one location with a concentration above 2.5 ppm was a common carp sample from the Colorado River at Blythe (2.5 ppm).

Foe (2010) reported similar findings for selenium concentrations in largemouth bass from the Delta. Samples collected from 2000-2007 were analyzed. All of these samples were well below 2.5 ppm – the maximum concentration measured was 0.89 ppm in a fish from the San Joaquin River at Potato Slough.

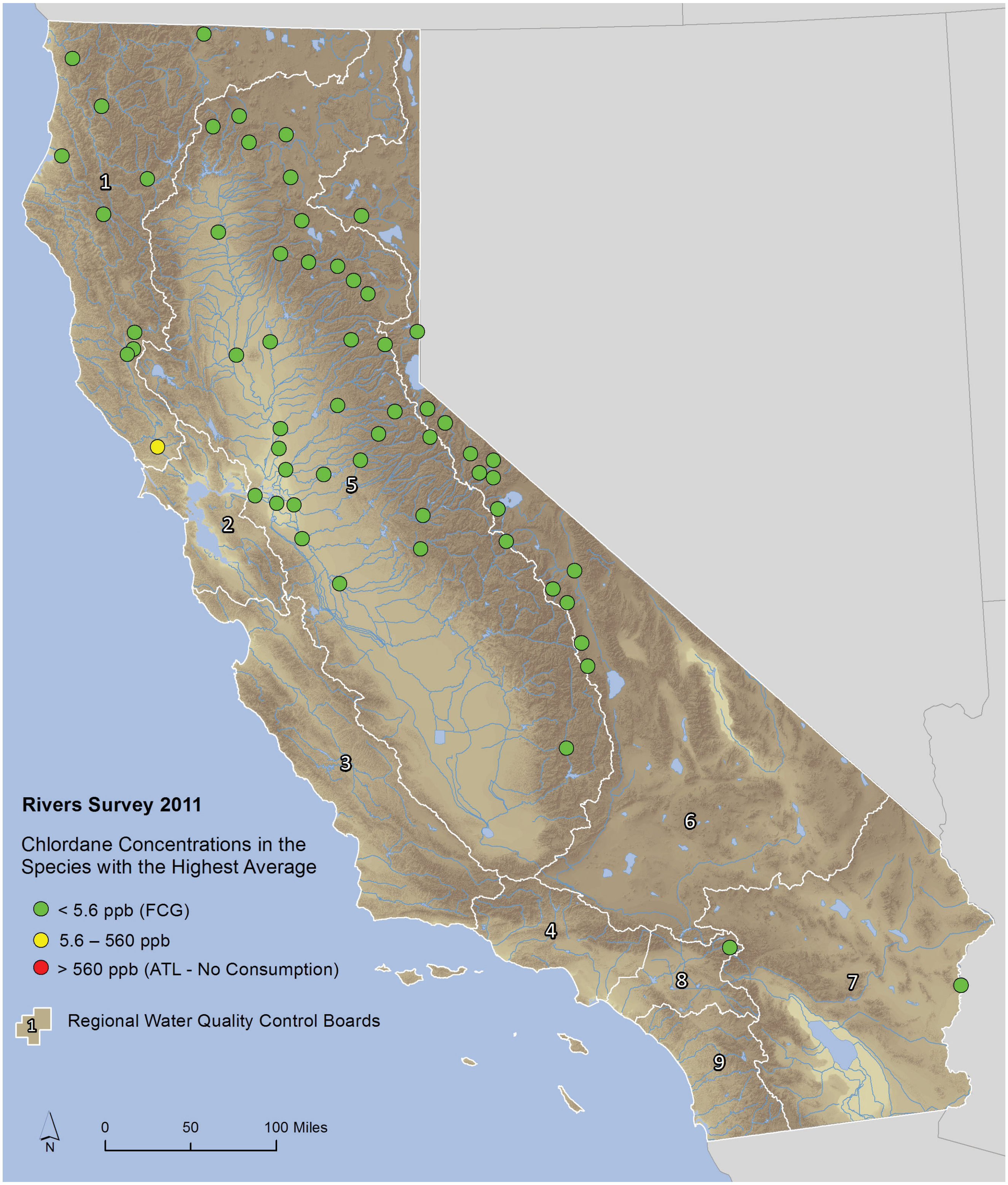

Figure 15. Spatial patterns in chlordane concentrations among locations sampled in the 2011 Rivers and Streams Survey. Each point represents the highest average concentration among the species sampled at each location.

SECTION 4 OVERALL SUMMARY OF THE RIVERS AND STREAMS SURVEY

This section begins by addressing the two following two management questions that this Survey was designed to answer, and then outlines remaining information needs.

STATUS OF THE FISHING BENEFICIAL USE

For popular fish species, what percentage of popular fishing areas have low enough concentrations of contaminants that fish can be safely consumed?

The Rivers and Streams Survey documented widespread, and in a limited area severe, impact of bioaccumulative contaminants on the fishing beneficial use. Methylmercury is the contaminant that poses the greatest concern for consumers of fish caught in California rivers and streams. Thirteen percent of the river and stream locations sampled had a species that exceeded OEHHA's no consumption advisory tissue level of 0.44 ppm. None of the other contaminants measured had a concentration above a no consumption ATL. Therefore, some degree of safe fish consumption was possible, considering the entire suite of species present, at 87% of the 63 locations sampled.

It should be noted that variation among species was significant. Other less-contaminated species were frequently present alongside the species with high concentrations at the contaminated locations, so that safe fish consumption at a frequency of more than one serving per week is possible at the vast majority of these locations if the cleaner species are selected. Comparing the data to a higher (i.e., more conservative) standard of safety, 28 of the 63 locations (44%) had at least one species that can be safely consumed at a higher consumption rate of 3 servings per week (i.e., below the OEHHA 2 serving ATLs for all contaminants).

The state has used a threshold of 0.30 ppm in the past for 303(d) listing decisions related to methylmercury impacts on the fishing beneficial use. These listings are based on concentrations in the most contaminated species in each water body. In rivers and streams, 13 of the 63 locations (21%) had a most contaminated species exceeding 0.30 ppm. Mercury TMDLs in the state have been developed for several water bodies, including Clear Lake, Los Angeles Area lakes, San Francisco Bay, the Delta, and others. These TMDLs include objectives for methylmercury in fish tissue in the range of 0.20 ppm. This value was exceeded in 16 of the 63 (25%) of the locations sampled.

OEHHA's Fish Contaminant Goals (FCGs) have sometimes been used in 303(d) listing decisions for organic contaminants. Based on comparison to these thresholds, a significant proportion of the river and stream locations also have problematic concentrations of organic contaminants. Dieldrin exceeded its FCG of 0.46 ppb at 48% of the locations and PCBs exceeded the 3.6 ppb FCG at 32% of the locations. Exceedance of FCGs for the other organic contaminants was lower: 5% for DDTs and 2% for chlordanes.

It is also useful to summarize the status of contamination by fish species. Trout, salmon, and striped bass are the most popular species for consumption. Trout and salmon generally have low concentrations of all contaminants. Striped bass were collected only from the Bay-Delta Estuary, and were among the most contaminated species, with an average methylmercury concentration just below the no consumption ATL. Other species with high concentrations at one or more locations included largemouth and smallmouth bass, Sacramento pikeminnow, and Sacramento sucker. The bass and pikeminnow have a high trophic position. The moderate to high concentrations in Sacramento sucker are a bit surprising given their low trophic position.

THE NEED FOR FURTHER SAMPLING FOR DEVELOPMENT OF CONSUMPTION GUIDELINES

Should additional sampling of contaminants in sport fish (e.g., more species or larger sample size) in specific areas be conducted for the purpose of developing comprehensive consumption guidelines?

The locations identified as having high concentrations in this Survey already have consumption guidelines in place, with the one exception of the Laguna de Santa Rosa, which is a popular fishing location. This location had a high methylmercury concentration in largemouth bass (0.52 ppm) and also had moderate concentrations of PCBs and dieldrin (34 and 1.7 ppb in common carp, respectively).

OTHER MANAGEMENT IMPLICATIONS

A TMDL is already in place for methylmercury in the Delta, and the other locations found to have high methylmercury concentrations are already on the 303(d) List.

The spatial patterns observed in this dataset are suggestive of some of the sources and other factors that drive methylmercury accumulation in sport fish in California rivers and streams. The high methylmercury concentrations around the periphery of the Delta and in its nearby tributaries are largely driven by legacy contamination tracing back to historic gold and mercury mining (Wood et al. 2010). The lower concentrations in the central Delta are thought to be a result of photodemethylation and settling of particle-associated methylmercury in the slow-moving waters of that region (Wood et al. 2010). Atmospheric deposition supplies mercury to water bodies throughout the state, and environmental conditions in some of these ecosystems favor the net production of methylmercury and accumulation in the food web. Methylmercury concentrations measured in high elevation water bodies tend to be low because of the predominance of rainbow trout, which have a relatively low trophic position and are often transplanted fish from hatcheries. High elevation locations where self-sustaining trout populations or other species are present often have moderate or even high methylmercury in fish. Hetch Hetchy Reservoir was a prime example in the Lakes Survey (Davis et al. 2010), where large, resident brown trout had high methylmercury concentrations. In some instances, local factors may contribute to these observations. For example, East Walker River below Bridgeport Reservoir had one rainbow trout with a relatively high concentration for that species (0.17 ppm), along with a Sacramento blackfish composite sample with a fairly high concentration (0.36 ppm) – these findings suggest relatively high methylmercury concentrations in water or sediment in this water body. This location is just below a reservoir, a situation which could lead to bioaccumulation if the reservoir releases are high in methylmercury.

As noted in the past (Wiener et al. 2004), the high concentrations of methylmercury in sport fish and other indicator species in the Delta region have significant implications for the ambitious restoration projects that are occurring in this region. Wiener et al. presented a strategy for science and adaptive management to support ecological restoration in a manner that minimizes biotic exposure to methylmercury. Sustained bioaccumulation monitoring is a central element of the strategy.

REMAINING INFORMATION GAPS

Information needs relating to the spatial extent of bioaccumulation impact on the fishing beneficial use in California rivers and streams have been reasonably well characterized by the combination of this Survey and past monitoring. This Survey indicates that the main problem area is the Delta and its nearby tributaries, where monitoring has been relatively thorough and consumption advisories are already in place. Fish from a few water bodies outside of this region had concentrations above 0.20 ppm, mostly for species other than rainbow trout, which is the most abundant species in the higher elevation water bodies included in this Survey. More thorough sampling of species less abundant than rainbow trout in higher elevation water bodies might reveal more locations with concentrations above 0.20 ppm, but the primary targets for anglers have been characterized fairly well.

Information on long-term trends is a major information gap. Even in the relatively heavily sampled Delta region, few time series exist that allow for rigorous trend evaluation. Methylmercury is the contaminant for which trend monitoring is most needed. Methylmercury accumulation in the state's rivers and streams can be affected by changes in regional or global emissions of mercury to the atmosphere or to other broad-scale factors such as climate change. Long-term trend monitoring to evaluate the effectiveness of control programs is also needed.

Information on the potential effect of methylmercury on wildlife dependent on river and stream habitat is also needed. Concentrations of methylmercury in river and stream food webs in some areas are high enough to pose risks to birds, mammals, and the fish themselves.

Monitoring of contaminants of emerging concern in fish from select river and stream locations, near major discharges of municipal wastewater or agricultural drainage, would also be valuable.

In summary, the following next steps are recommended for evaluation the impact of contaminant bioaccumulation on beneficial uses in California rivers and streams:

1. more thorough sampling of species less abundant than rainbow trout in higher elevation water bodies to provide for a more accurate assessment of contaminant impacts on the fishing beneficial use;
2. establishment of stations where long-term time series are created using a rigorous sampling design to evaluate trends;
3. evaluation of methylmercury risks to wildlife dependent on river and stream habitat; and
4. monitoring of contaminants of emerging concern in fish from select river and stream locations.

REFERENCES

Allen T. and Southwick R. 2008. Sportfishing in America: an economic engine and conservation powerhouse. American Sportfishing Association, Alexandria, VA.

Beckon, W.N., M.C.S. Eacock, and A.G. Gordus. 2010. Biological Effects on the Grassland Bypass Project. Pp. 105-172 in SFEI. 2010. Grassland Bypass Project Annual Report: 2006-2007. San Francisco Estuary Institute, Oakland, CA. http://www.sfei.org/sites/default/files/GBP%20Annual%20Report%200607%20for%20web_0.pdf

Bioaccumulation Oversight Group. 2011. Sampling and Analysis Plan for a Screening Study of Bioaccumulation in California Rivers and Streams. Prepared for the Surface Water Ambient Monitoring Program, California Water Resources Control Board, Sacramento, CA. http://www.waterboards.ca.gov/water_issues/programs/swamp/docs/rivers_study/monplan11.pdf

Bonnema, A. 2011. Quality Assurance Program Plan for a Screening Study of Bioaccumulation in California Rivers and Streams. Moss Landing Marine Labs. Prepared for the Surface Water Ambient Monitoring Program, California Water Resources Control Board, Sacramento, CA.

Davis, J.A., M.D. May, G. Ichikawa, D. Crane. 2000. Contaminant Concentrations in Fish from the Sacramento-San Joaquin Delta and Lower San Joaquin River, 1998. San Francisco Estuary Institute, Richmond, CA.

Davis, J. A., B. K. Greenfield, G. Ichikawa, and M. Stephenson. 2003. Mercury in sport fish from the Delta region (Task 2A). An assessment of the ecological and human health impacts of mercury in the Bay-Delta watershed. CALFED Bay-Delta Mercury Project, Sacramento, CA.

Davis, J.A., J. L. Grenier, A. R. Melwani, S. N. Bezalel, E. M. Letteney, E. J. Zhang, M. Odaya. 2007. Bioaccumulation of Pollutants in California Waters: A Review of Historic Data and Assessment of Impacts on Fishing and Aquatic Life. Prepared for the Surface Water Ambient Monitoring Program, California State Water Resources Control Board, Sacramento, CA.

Davis, J.A., B.K. Greenfield, G. Ichikawa, and M. Stephenson. 2008. Mercury in sport fish from the Sacramento–San Joaquin Delta region, California, USA. Science of the Total Environment 391: 66-75.

Davis, J.A., A.R. Melwani, S.N. Bezalel, J.A. Hunt, G. Ichikawa, A. Bonnema, W.A. Heim, D. Crane, S. Swenson, C. Lamerdin, and M. Stephenson. 2010. Contaminants in Fish from California Lakes and Reservoirs, 2007-2008: Summary Report on Two-Year Screening Survey. A Report of the Surface Water Ambient Monitoring Program (SWAMP). California State Water Resources Control Board, Sacramento, CA. http://www.swrcb.ca.gov/water_issues/programs/swamp/lakes_study.shtml

Davis, J.A., K. Schiff, A.R. Melwani, S.N. Bezalel, J.A. Hunt, R.M. Allen, G. Ichikawa, A. Bonnema, W.A. Heim, D. Crane, S. Swenson, C. Lamerdin, and M. Stephenson. 2011. Contaminants in Fish from the California Coast, 2009: Summary Report on Year One of a Two-Year Screening Survey. A Report of the Surface Water Ambient Monitoring Program (SWAMP). California State Water Resources Control Board, Sacramento, CA. http://www.waterboards.ca.gov/water_issues/programs/swamp/coast_study.shtml

Davis, J.A., J.R.M. Ross, S.N. Bezalel, J.A. Hunt, A.R. Melwani, R.M. Allen, G. Ichikawa, A. Bonnema, W.A. Heim, D. Crane, S. Swenson, C. Lamerdin, M. Stephenson, and K. Schiff. 2012. Contaminants in Fish from the California Coast, 2009-2010: Summary Report on a Two-Year Screening Survey. A Report of the Surface Water Ambient Monitoring Program (SWAMP). California State Water Resources Control Board, Sacramento, CA.

Greenfield, B.K., Jahn, A., 2010. Mercury in San Francisco Bay forage fish. Environ. Pollut. 158, 2716–2724.

Grenier et al 2007. Final Technical Report: California Bay-Delta Authority Fish Mercury Project – Year 1 Annual Report, Sport Fish Sampling and Analysis. San Francisco Estuary Institute, Oakland, CA. http://www.sfei.org/cmr/fishmercury

Hebert, C.E., Keenleyside, K.A., 1995. To normalize or not to normalize? Fat is the question. Environmental Toxicology and Chemistry 14 (5), 801–807.

Klasing, S. and R. Brodberg. 2008. Development of Fish Contaminant Goals and Advisory Tissue Levels for Common Contaminants in California Sport Fish: Chlordane, DDTs, Dieldrin, Methylmercury, PCBs, Selenium, and Toxaphene. California Office of Environmental Health Hazard Assessment, Sacramento, CA.

Melwani et al. 2007. California Bay - Delta Authority Fish Mercury Project Year 2 Annual Report: Sport Fish Sampling and Analysis. San Francisco Estuary Institute, Oakland, CA.

Melwani, A.R., S.N. Bezalel, J.A. Hunt, J.L. Grenier, G. Ichikawa, W. Heim, A. Bonnema, C. Foe, D.G. Slotton, and J.A. Davis. 2009. Spatial trends and impairment assessment of mercury in sport fish in the Sacramento–San Joaquin Delta watershed. Environmental Pollution 157: 3137–3149.

Moyle PB. Inland fishes of California. Berkeley: University of California Press; 2002. 502 pp.

Sandheinrich, M.B., Wiener, J.G., 2011. Methylmercury in freshwater fish: recent advances in assessing toxicity of environmentally relevant exposures. Pp 169-190 in Beyer, W.N. Meador, J.P. (eds.) 2011. Environmental Contaminants in Biota: Interpreting Tissue Concentrations. CRC Press, Boca Raton, FL, USA.

Stienstra, T. 2004. FOGHORN OUTDOORS CALIFORNIA FISHING The Complete Guide to Fishing on Lakes, Streams, Rivers, and Coasts, 7th Edition. Emeryville (CA): Avalon Travel Publishing. 697 p.

USEPA. 2000. Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories: Volume 1, Fish Sampling and Analysis, Third Edition. EPA 823-R-93-002B-00-007. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

USEPA. 2001. Water Quality Criterion for the Protection of Human Health: Methylmercury. EPA-823-R-01-001. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Wiener, J. G., C. C. Gilmour, and D. P. Krabbenhoft. 2004. Mercury strategy for the Bay-Delta ecosystem: unifying framework for science, adaptive management, and ecological restoration. CALFED Bay-Delta Mercury Project, Sacramento, CA.

Wiener, J.G., R.A. Bodaly, S.S. Brown, M. Lucotte, M.C. Newman, D.B. Porcella, R.J. Reash, and E.B. Swain. 2007. Monitoring and evaluating trends in methylmercury accumulation in aquatic biota. Chapter 4 in R. C. Harris, D. P. Krabbenhoft, R. P. Mason, M. W. Murray, R. J. Reash, and T. Saltman (editors) Ecosystem responses to mercury contamination: indicators of change. SETAC Press, Pensacola, Florida.

Wood, M.L, C.G. Foe, J. Cooke, and S.J. Louie. 2010. Sacramento – San Joaquin Delta Estuary TMDL for Methylmercury. Central Valley Regional Water Quality Control Board, Rancho Cordova, CA. http://www.waterboards.ca.gov/rwqcb5/water_issues/tmdl/central_valley_projects/delta_hg/april_2010_hg_tmdl_hearing/apr2010_tmdl_staffrpt_final.pdf

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